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Kootenai River Fisheries Investigation

Stock Status of Burbot

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FISHERY RESEARCH

KOOTENAI RIVER FISHERIES INVESTIGATION: STOCK STATUS OF BURBOT

ANNUAL PROGRESS REPORT
April 1, 2003—March 31, 2004

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IDFG Report Number 04-41
December 2004

Kootenai River Fisheries Investigation:
Stock Status of Burbot

2004 Annual Report

Chapter 1—Project Progress Report

Chapter 2—Status and Population Dynamics of Burbot in the Kootenai River, Idaho and British Columbia, Canada

By

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TABLE OF CONTENTS

Page

Table of Contents, continued.

LIST OF TABLES

List of Tables, continued.

Page

LIST OF FIGURES

List of Figures, continued.

List of Figures, continued.

Page

List of Figures, continued.

Page

LIST OF APPENDICES

List of Appendices, continued.

CHAPTER 1—PROJECT PROGRESS REPORT

ABSTRACT

The main objective of this investigation was to monitor movement and spawning activity of burbot *Lota lota* in the Kootenai River, Idaho and British Columbia, Canada during the winter of 2003-2004. Due to low precipitation and snow pack, as well as low levels of Lake Koocanusa, the U.S. Army Corps of Engineers refrained from releasing discharges >113 m^3/s from Libby Dam for most of the winter. This situation provided suitable conditions for burbot migration and spawning in the mainstem river. Hoop nets captured 19 burbot, which ranged from 447 mm to 760 mm TL (mean = 630 mm) and weighed from 420 g to 4,032 g (mean = 1,937 g) with a mean W_r of 99. One burbot (burbot 214) was captured for the fifth time since its first capture in 2000, and each capture was near Ambush Rock (rkm 244.4-244.8). Eleven burbot were tagged with five-month duration external sonic transmitters, and a 12th burbot, tagged with a 14-month transmitter, has been monitored since 2001. During the post-spawn period, three sonic-tagged burbot exhibited downstream and sedentary movement patterns, while five remained at Ambush Rock. Concentrations of tagged burbot near Ambush Rock (rkm 244.5) during January and February 2004 (eight tagged fish) may suggest that this area is critical spawning habitat. The appearance of burbot at Ambush Rock during the spawning period and upstream movements of tagged fish (PIT and sonic tagged) in previous years during the low discharges help validate results suggesting that discharges <113 m^3/s will permit burbot migration and may increase spawning habitat. Though it seems apparent that the Ambush Rock area is an important burbot spawning ground, no adult burbot were recaptured after the spawning period and no burbot larva were caught, despite considerable sampling efforts during the winter of 2003-2004.

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INTRODUCTION

In Idaho, burbot *Lota lota* are endemic only to the Kootenai River (spelled Kootenay for Canadian waters) (Simpson and Wallace 1982). Burbot in the Kootenai River (Figure 1) once provided an important winter fishery to residents of northern Idaho. This fishery and that of Kootenay Lake, British Columbia (BC), Canada (Paragamian et al. 2000) may have been the most robust in North America (Paragamian and Hoyle 2005). Some anglers reported catching up to 40 burbot per night during winter setline fishing (Paragamian 1994a). The annual harvest of burbot from the Kootenai River by sport and commercial fisherman in Idaho prior to 1972 may have been in the tens of thousands of kg. Three commercial anglers alone harvested an estimated 2,150 kg in 1958 (Idaho Department of Fish and Game [IDFG] Regional Archives, unpublished). Burbot caught during the winter fishery are thought to have been part of a spawning migration from the lower river and Kootenay Lake in British Columbia. However, after construction and operation of Libby Dam by the U.S. Army Corps of Engineers (USACE) in 1972, the fishery rapidly declined and was closed in 1992. Concomitant to the collapse in Idaho was the collapse of the burbot fishery in Kootenay Lake, BC (Paragamian et al. 2000). Operation of Libby Dam for hydroelectric power and flood control has created major changes in the river's seasonal discharge, particularly during the winter when burbot spawn (Figure 2). The temperature regime and nutrient supply of the Kootenai River are also thought to be important factors for burbot spawning and recruitment; they too have changed since construction of Libby Dam (Partridge 1983; Snyder and Minshall 1996; Richards 1996).

The Kootenai River Fisheries Investigation was initiated in 1993 by the IDFG to document burbot abundance, distribution, size structure, reproductive success, and movement, and to identify factors limiting burbot in the Kootenai River. Few burbot were captured between rkm 246 (Bonners Ferry) and the Montana border (rkm 275) from 1993 through 1994 (Paragamian 1994a). There has been little evidence of burbot reproduction in the Idaho reach. Only one juvenile burbot was captured from 1993 through 1998, and only one larval fish was collected. However, numerous size-classes of burbot were in the catch, indicating some burbot were reproducing successfully, albeit insufficiently to sustain the population. Previous studies have failed to document a spawning run of burbot from the lower river or Kootenay Lake. However, cooperative sampling in the BC reach of the river with the British Columbia Ministry of Water, Land, and Air Protection (BCMWLAP) documented spawning burbot in the Goat River, BC (Paragamian 2000), and during the winter of 2000-2001 a "spawning ball" of burbot was documented at Ambush Rock (Kozfkay and Paragamian 2002).

Studies completed during the winter of 1997-1998 indicated discharge management at Libby Dam likely affected burbot spawning migration during winter (Paragamian 2000). Movement of burbot with sonic transmitters was significantly higher during low discharge test conditions designed to mimic pre-dam Kootenai River discharge. Movement upstream was also significantly higher during low discharge tests (170 m^3/s) than the control (170–736 m^3/s), despite the fact there were low discharges during the controls. Post-dam winter discharges are now three to four times greater than they were historically when conditions were relatively stable. Daily differences in discharge now range up to 652 m^3/s, a six-fold change. Fluctuating discharges from Libby Dam caused by hydropower production and floodwater evacuation appear to have continuously disrupted upstream migrations of burbot. The specific effect of this disruption to burbot spawning migration and spawning is unknown, but it may have reduced spawning fitness or stamina or affected timing of burbot spawning. One or all of these possible factors could have been sufficient to contribute to reduced spawning success and recruitment.

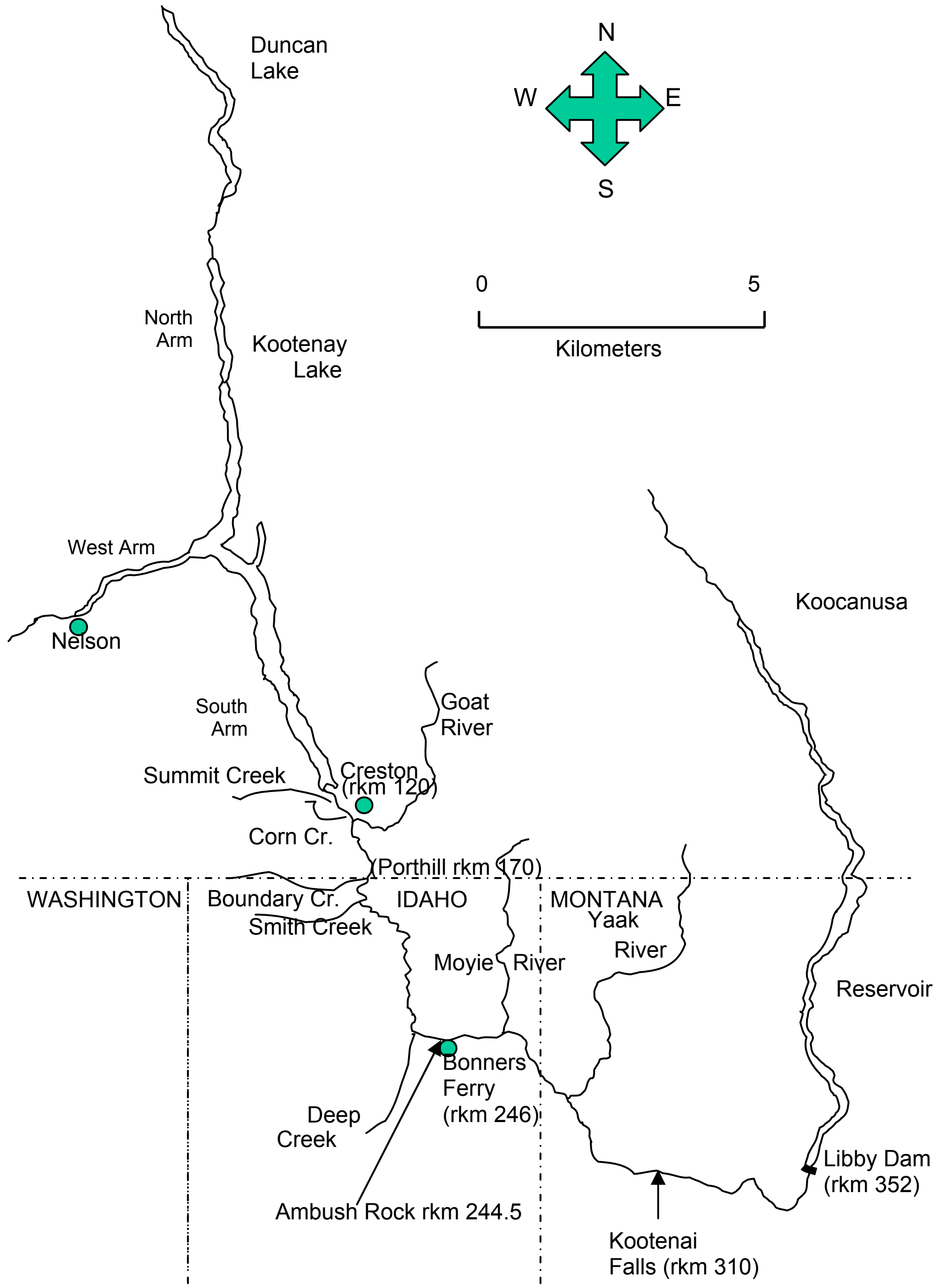

Figure 1. Location of the Kootenai River, Kootenay Lake, Lake Koocanusa, and major tributaries. The river distances from the northernmost reach of Kootenay Lake are in river kilometers (rkm) and are indicated at important access points.

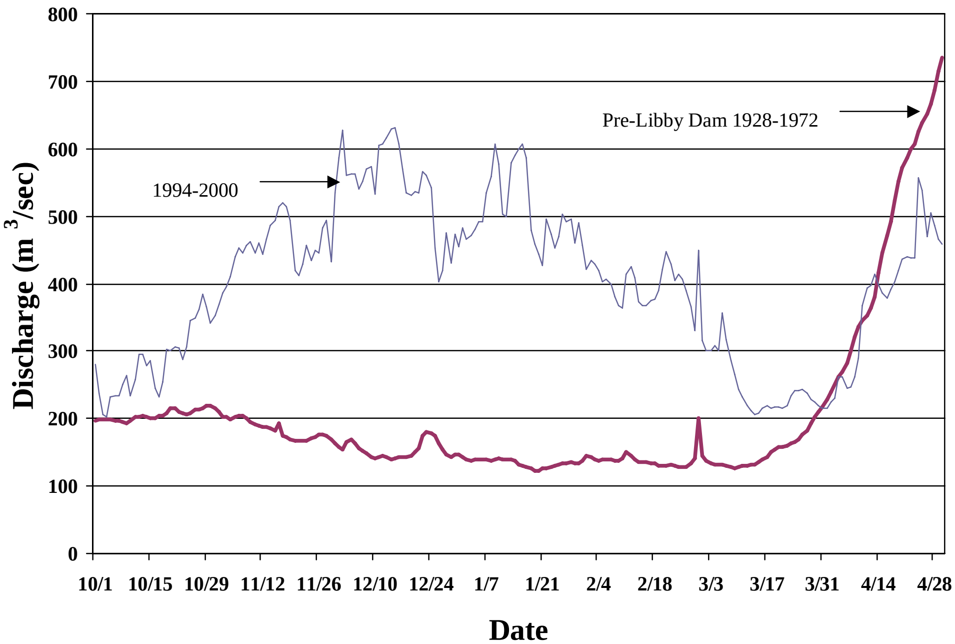

Figure 2. Mean monthly discharge of the Kootenai River at Porthill, Idaho, from 1962 through 1971 (pre-Libby Dam), and from 1994 through 2000 (post-Libby Dam).

Because burbot in the Kootenai River may be at risk of demographic extinction (Paragamian 2000), a Conservation Strategy (Anonymous 2002) was prepared to outline measures necessary to rehabilitate the burbot population. The Conservation Strategy indicated that operational discharge changes at Libby Dam must be implemented during winter to provide suitable conditions for burbot migration. However, the upper limit of discharge releases for adequate burbot spawning migration and flood control were unknown for inclusion in a more recent Conservation Agreement, a legally binding document that ensures river managers would cooperate in measures to recover burbot. Experimental discharges were proposed with the USACE and the Bonneville Power Administration (BPA) from 1998-2002 initially, and were set at 170 m^3/s from Libby Dam (similar to pre-dam winter discharges) for burbot spawning migration (Paragamian and Whitman 1999, 2000, and this study). The intention was to test the null hypothesis that discharges $\leq$300 m^3/s from the dam do not inhibit burbot migration distance or travel rate. However, studies were largely ineffective because of hydropower and flood management priorities of the BPA and the USACE from 1998 through 2000. Since test conditions were unachievable, an alternative evaluation was necessary (Paragamian et al. 2005). The objective was to examine existing telemetry records of burbot collected from 1994 through 2000 (Paragamian 1994b, 1995; Paragamian and Whitman 1996, 1997, 1998, 1999, 2000) to further determine how discharge factors affect burbot travel distance and travel rate. The seasonal distribution of movements found 30 (68%) of 44 “stepwise movements”

(movements of 5 km or more in 10 d or less) occurred when discharges were ≤300 m^3/s from Libby Dam and averaged 176 m^3/s. "Stepwise movements" of burbot were examined to assess possible statistically significant differences in movement when the number of days discharges from Libby Dam were ≤300 m^3/s (N = 15 and 186 days, low discharges) in comparison to the number of days discharges were ≥301 m^3/s (N = 11 and 538 days, high discharges). The Fisher Exact Test results indicated burbot moved more frequently during lower discharges. Consequently, it recommended that discharge for burbot prespawning migration should range from 113 to 300 m^3/s and average 176 m^3/s for a minimum of 90 d (mid November through mid February). Although these recommendations appear adequate, it is important that the discharge measures for burbot spawning migration be evaluated.

Post-Libby Dam temperature changes may be an additional factor affecting the spawning and recruitment of burbot in the Kootenai River. Partridge (1983) found temperature of the Kootenai River is now cooler in the summer and warmer in the winter by several degrees C. Burbot spawn at temperatures of 1-4°C (McPhail and Paragamian 2000), and even subtle temperature changes in the Kootenai River could have affected the timing and maturation rate of burbot. In addition, temperatures above 6°C have been found to cause mortality in larval burbot (Taylor and McPhail 2000). Thus, it is important to determine how these changes in the Kootenai River and its tributaries may have potentially affected burbot spawning migration, rate of maturity (annual gonad development), spawning synchrony, and possible larval survival.

GOAL

The fishery management goal of this study is to restore the burbot population in the Idaho reach of the Kootenai River to provide an annual sustainable harvest of burbot.

OBJECTIVES

1. Identify factors limiting burbot within the Idaho portion of the Kootenai River drainage and recommend management alternatives to restore the population to self-sustaining levels.

2. Define factors limiting burbot migration and reproductive success to improve survival and recruitment of young burbot.

3. Test the null hypothesis (H_o) that winter operation of Libby Dam (>300 m^3/s) does not affect burbot migration distance or travel rate.

STUDY AREA

The Kootenai River is one of the largest tributaries to the Columbia River. Originating in Kootenay National Park, BC, the river discharges south into Montana, where Libby Dam impounds water into Canada and forms Lake Koocanusa (Figure 1). From Libby Dam, the river discharges west and then northwest into Idaho, then north into BC and Kootenay Lake. The Kootenai River at Porthill, Idaho, drains about 35,490 km^2. The reach in Idaho is 106 km long. Kootenay Lake drains out the West Arm, and eventually the river joins the Columbia River near Castlegar, BC.

The Kootenai River presents three different channel and habitat types as it passes through Idaho. As the river enters Idaho, steep canyon walls and a gradient of about 0.6 m/km typify the corridor. The river begins a short braided reach about 1 km below the Moyie River, and then downstream at Bonners Ferry the river transitions to a lower gradient of approximately 0.02 m/km and meanders through a broad flood plain. Tributary streams of the Kootenai River are typically high gradient as they pass through mountain canyons but revert to lower gradients when they reach the valley floor, where they have been altered (e.g., diked, channelized, and meet the river at right angles) to improve agriculture lands.

METHODS

Discharge and Temperature

Daily discharge and temperature values for the Kootenai River were obtained from the USACE and the U.S. Geological Survey (USGS) office in Sandpoint, Idaho. A systems operation request (SOR) for winter of 2003-2004 by the Kootenai Valley Resource Initiative's (KVRI) Burbot Recovery Committee called for a maximum discharge from Libby Dam of 15 kcfs (425 m^3/s) from December 1 through 22, 2003. It also called for maximum discharge of 10 kcfs (283 m^3/s) from December 23, 2003 through January 31, 2004, with a preference during the later portion of the request for an average of 7.3 kcfs (207 m^3/s).

The KVRI also requested that Libby Dam release the coolest water possible for the winter of 2003-2004. Temperatures of water released from Libby Dam was to be at or near the coolest available in the range of the selective withdrawal system for the duration of the SOR. In October and November (pre-SOR), cooler water is available for release in those months, and the USACE could target them to at least the lower limit of the Selective Withdrawal Agreement. It is hypothesized these lower temperatures could be beneficial to burbot because lower temperatures would more closely approximate natural pre-dam conditions (Partridge 1983). Temperature for the Kootenai River was recorded at four locations: Bonners Ferry, Ambush Rock, Copeland, and Porthill, Idaho and Libby Dam, Montana.

A HOBO® or StowAway® XI temperature logger was used to monitor daily water temperatures for Smith and Boundary creeks in Idaho, Corn, and Summit creeks and the Goat River in BC and the Kootenai River at Porthill, Idaho from October 2003 through March 2004. At each location, mean temperature was calculated from five evenly spaced daily measurements. A temperature logger was deployed less than 50 meters upstream from each tributary creek confluence with the Kootenai River. In Summit and Boundary creeks, an additional thermograph was placed approximately 500 meters upstream to assess the infiltration of warmer water from the Kootenai River. These loggers assessed whether infiltration of Kootenai River water into these creek mouths was substantial, in which case the coldwater inputs that burbot may use as migration cues would be obscured (Paragamian 2000). Although no burbot spawning has been documented in tributaries recently, Summit and Boundary creeks were anecdotal historical burbot spawning areas.

Sampling Adult Burbot

Technicians sampled adult burbot from early November 2003 through March 22, 2004 with up to 15 baited hoop nets. Hoop nets had a maximum diameter of 0.61 m (see Paragamian

1995 for a description of the nets and the method of deployment). Nets were deployed in deep (usually the thalweg) areas of the Kootenai River between Ambush Rock (rkm 244.5) near Bonners Ferry, Idaho, and Nicks Island (rkm 144) near Creston, BC. We also sampled three tributary streams including Deep Creek near Bonners Ferry, Idaho (rkm 240); Boundary Creek, which enters the Kootenai River at Porthill, Idaho (rkm 170); and the Goat River, near Creston, BC (rkm 152).

We usually lifted nets on Monday, Wednesday, and Friday of each week. Fish captured in hoop nets were identified by species, enumerated, measured for total length (TL), and weighed (g). All burbot were implanted with a passive integrated transponder (PIT) tag in the left opercular muscle. Sex of most burbot could not be determined because biopsies were not performed in an effort to reduce stress. Relative weight (W_r; Fisher et al. 1996) was calculated for each burbot captured. Burbot captured in a companion study (Paragamian et al. in press) were also included in some of the statistics of this report. This companion study examined the use of tributary streams in Idaho by burbot during the spawning season. Burbot are included because statistics of all fish captured in either investigation are included in the same long-term database and all were part of the same Kootenai River population.

Burbot Telemetry

Sonic transmitters were used to track the movement of burbot during the winter of 2003-2004. One 14 month 74 kHz sonic tagged burbot, which had been surgically implanted during the 2001-2002 field season, was tracked throughout the summer and monitored several times a month when possible. For the 2003-2004 season burbot were fitted with five month, 3.7 g externally attached 80 kHz sonic tags (Sonotronics, IBT-96-5) as a less intrusive means to monitor movement. Sonic telemetry was conducted via boat.

Attachment for sonic transmitters was similar to 2002-2003 (Paragamian and Hoyle 2005; Figure 3). Sonic tags came equipped with previously drilled holes. After anesthetizing the burbot with MS-222, FireLine™ was fed through the skin in the anterior portion of the second dorsal fin with a #12 gage 3.8 cm stainless steel needle. Two plastic 2.5 cm diameter Peterson discs were placed on the opposite side of the tag to prevent excessive chafing, and the FireLine™ was crimped with steel sleeves. This procedure took between 10 and 15 min to complete. After the transmitter was attached, the burbot was allowed to recover in fresh river water. Before deployment, the transmitter was checked to make sure it was functioning properly.

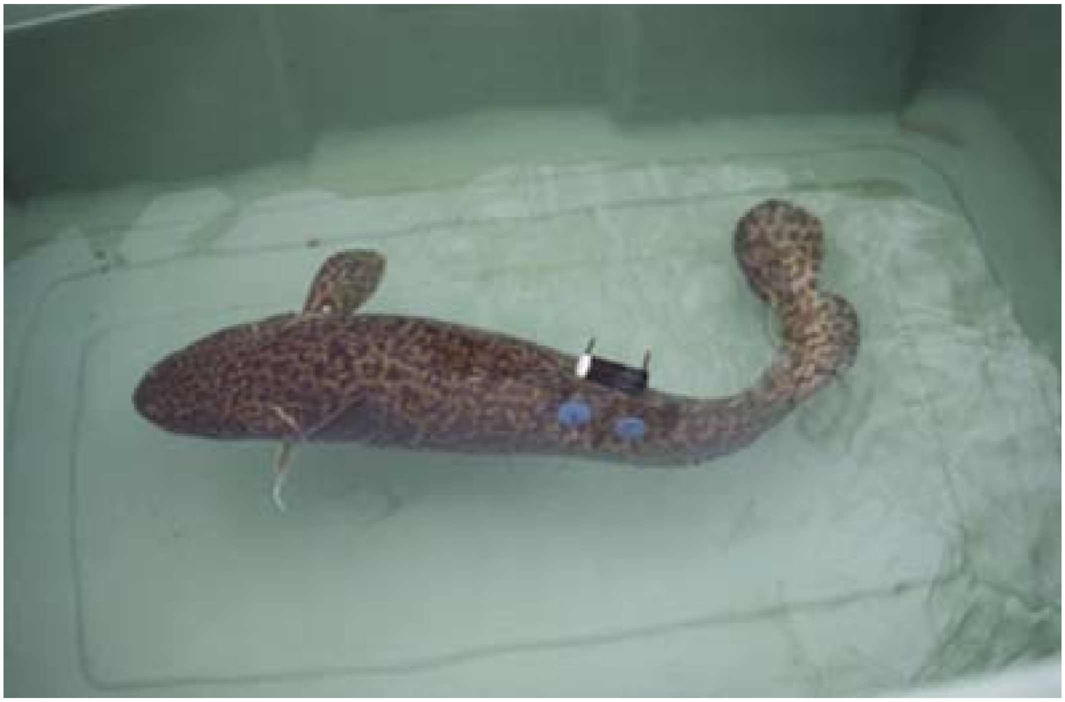

Figure 3. A Kootenai River burbot with an externally attached 80 kHz sonic tag. Note the size and placement of the transmitter.

Larval Sampling

½ meter net tows—Larval burbot were sampled in the Kootenai River towing paired ½ m nets (mouth area = 0.79 m^2) with a boat 8 m in length. One net was towed at the surface and a second at approximately 1.5 m of depth below the surface. In water less than 2 m, nets were towed near the bottom. Gurley 2030R current meters were mounted in the mouth of each net, and tows were made in a downstream direction; the boat motor (150 hp) was operated at 1,000 rpm to maintain uniform towing speed relative to current velocity. Tows were made at mid channel near Ambush Rock (rkm 244.5) because of shallow water and debris near the river margins. Tows downstream to the mouth of the Kootenai River (rkm 124.7) were conducted near the shoreline. Effort was calculated using total towing time and rotation counts per second from the discharge meters x mouth area (0.79 m^2) to calculate the total volume of water filtered through each net.

Light traps—Technicians also sampled for larval burbot with light traps described by Fisher (2000). Light traps were made from four plastic cylinders joined laterally, described as a quatrefoil measuring approximately 25 cm high by 30 cm wide. Traps were suspended near the water surface and powered by a 12 h photochemical stick. Up to six traps were deployed at dusk and checked the next morning.

RESULTS

Discharge and Temperature

Kootenai River Discharge

In the Canadian Rockies of the Kootenai basin, the winter of 2003-2004 was characterized by a lower than average snowpack ranging as low as 81% of normal (Jeff Laufle, USACE, personal communication). In mid November, discharge from Libby Dam was increased from about 113 m^3/s to 566 m^3/s for about five days. Discharges were then reduced to about 198 m^3/s for one day, then increased to about 566 m^3/s from December 2 through 14, 2003. After December 14, discharges were reduced to 283 to 340 m^3/s for several weeks and then reduced to about 113 m^3/s after January 17, 2004 for the remainder of the winter (Figure 4).

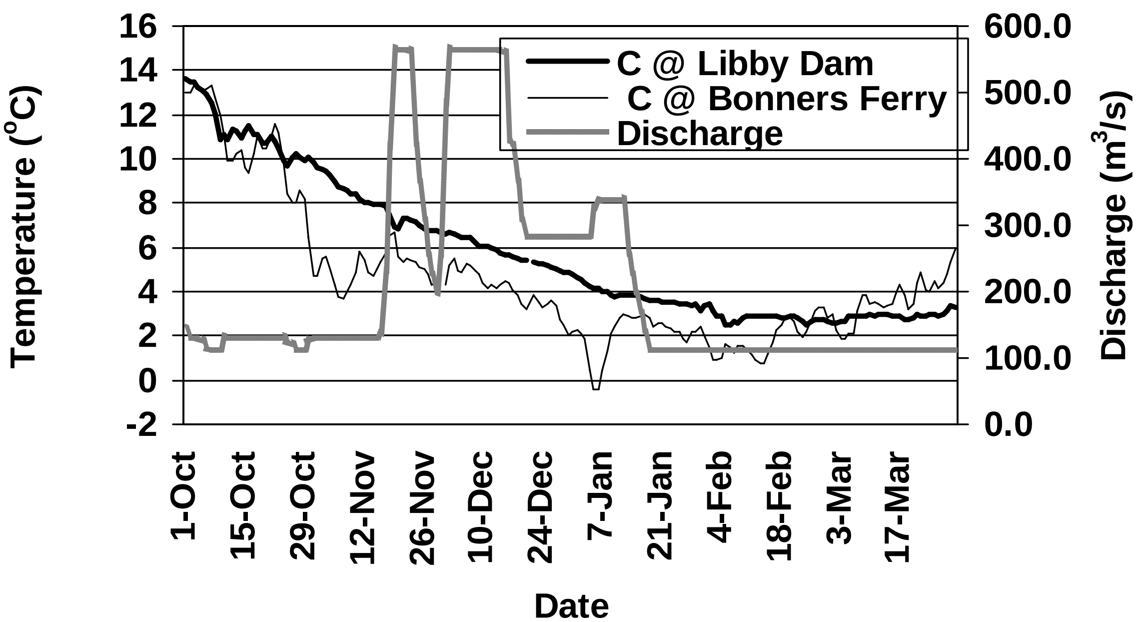

Figure 4. Kootenai River discharge at Libby Dam and river temperature at Libby Dam and Bonners Ferry, Idaho from October 1, 2003 through March 31, 2004.

Kootenai River Temperature

Mean water temperature at Libby Dam from October 1, 2003 through March 31, 2004 was 5.8°C, while it was 4.6°C at Bonners Ferry (Figure 4). Water below Libby Dam near Bonners Ferry cooled rapidly in October and then in December, where daily variations in temperatures were greater and the temperature approached 0°C more frequently compared to upstream. Increases in discharge from Libby Dam also tended to increase water temperature at Bonners Ferry (Figure 4). Water temperature recorded at Ambush Rock (rkm 244.5), Porthill (rkm 170), and Copeland (rkm 182) was recorded daily from December 29, 2003 through April 16, 2004. In general, water at these three stations was slightly warmer than Bonners Ferry for the same period of record (Figures 5, 6, and 7).

Tributary Temperatures

Water temperatures of four tributaries of the Kootenai River in Idaho and BC, Canada were monitored from November 18, 2003 through about April 16, 2004. The temperature recorder at the lower Summit Creek site was pulled from the water by a vandal and the recorder at Smith Creek was stolen. Mean water temperature of the Goat River was 1.9°C, while water temperature ranged from 0°C on December 14, 2003 to a high of 6°C on April 12, 2004 (Figure 8). At the Corn Creek site, mean water temperature was 2.6°C with a low approaching 0°C on January 10 and February 15, 2004 and a maximum of 6.3°C on April 4, 2004 (Figure 9). In lower Boundary Creek, mean water temperature at the mouth was 2°C and ranged from a minimum of –0.05°C from January 7-11, 2004 to a maximum of 4.5°C on April 4, 2004 (Figure 10). Mean temperature for upper Summit Creek was 1.1°C and ranged from below 0°C on February 22, 2004 to 5.3°C on March 30, 2004 (Figure 11).

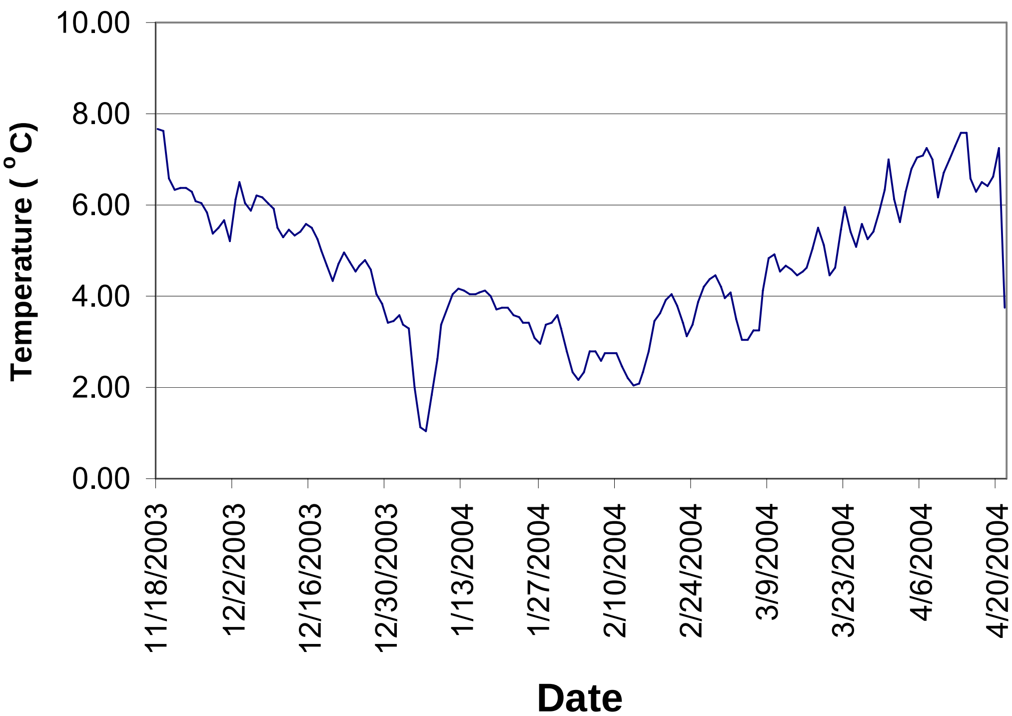

Figure 5. Kootenai River at Ambush Rock temperature November 18 through April 20, 2004.

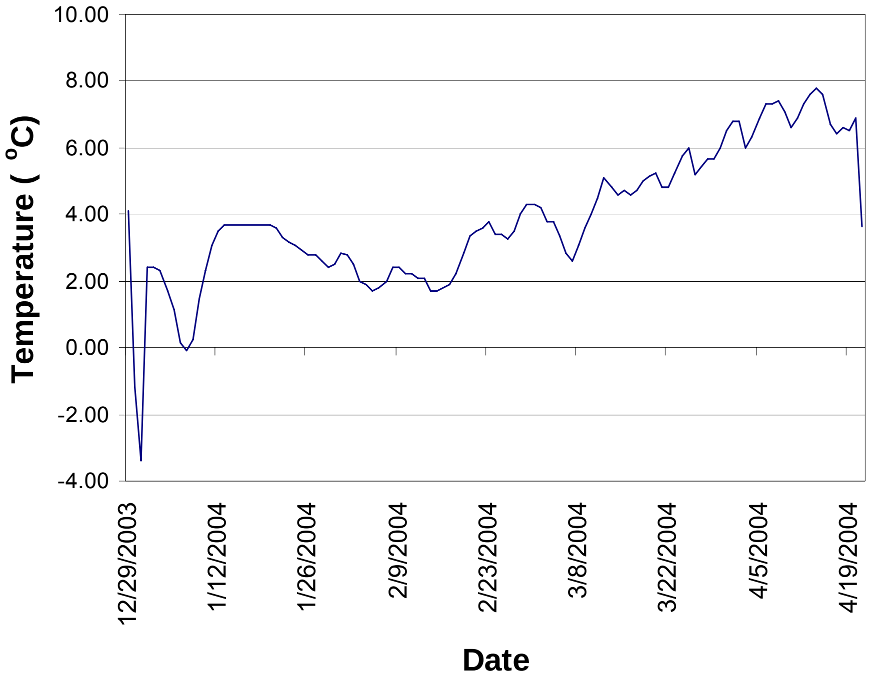

Figure 6. Kootenai River at Copeland, Idaho mean daily temperature (°C) profile December 29, 2003 through April 19, 2004.

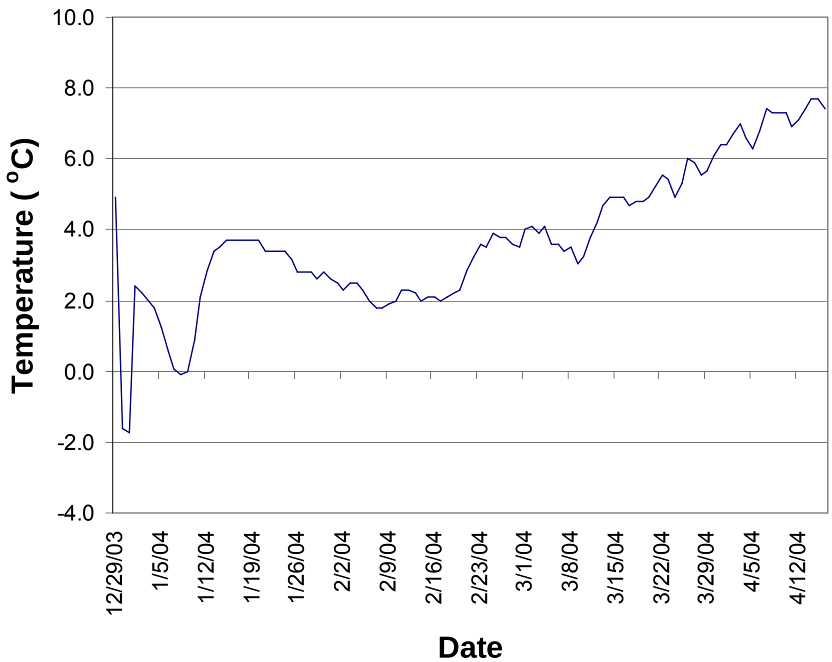

Figure 7. Temperature of the Kootenai River at Porthill, Idaho (rkm 170); temperature was recorded from December 29, 2003 through April 19, 2004.

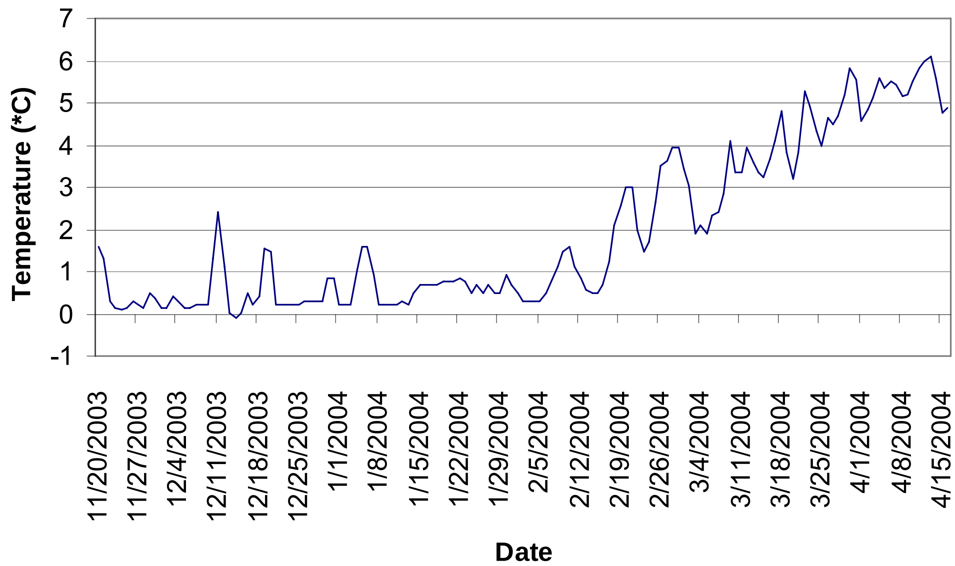

Figure 8. Goat River (°C) mean daily temperature profile November 20, 2003 through April 15, 2004.

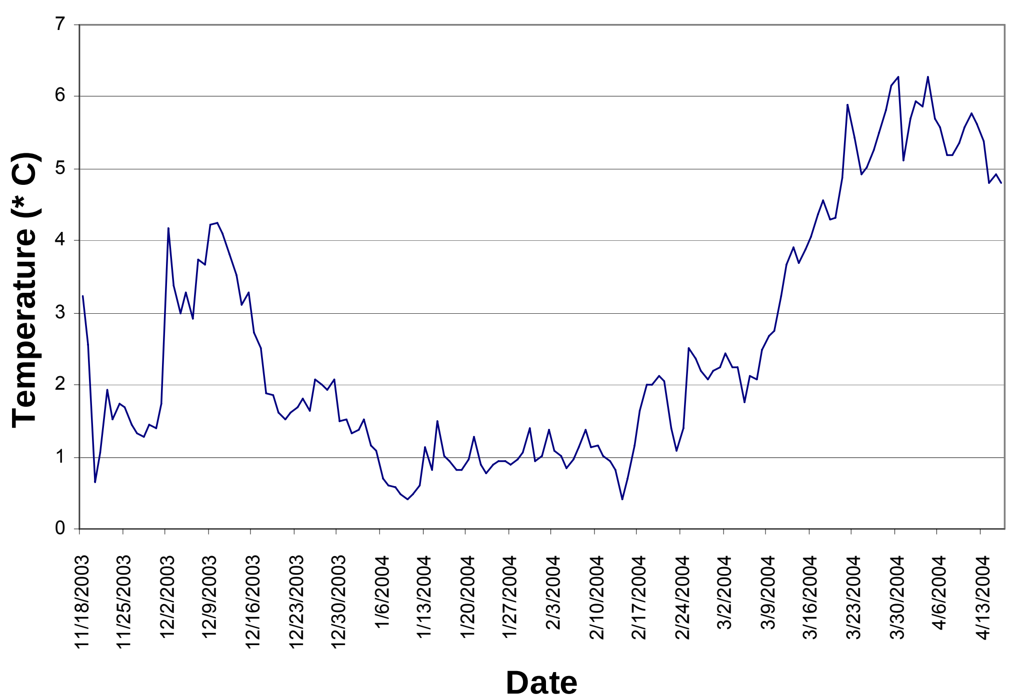

Figure 9. Corn Creek (°C) mean daily temperature profile November 20, 2003 through April 15, 2004.

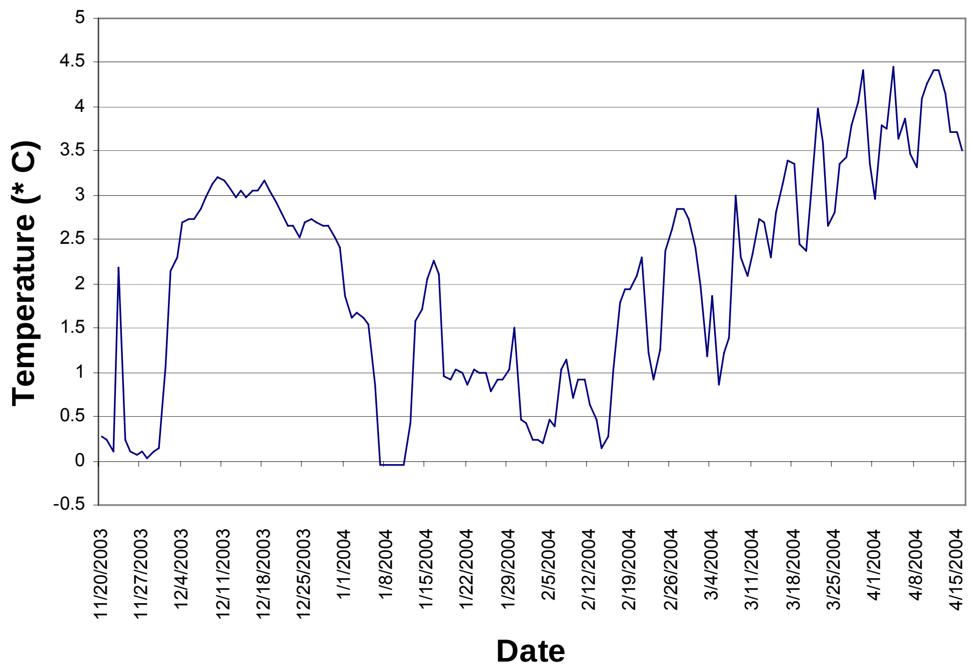

Figure 10. Boundary Creek (°C) mean daily temperature profile November 20, 2003 through April 15, 2004.

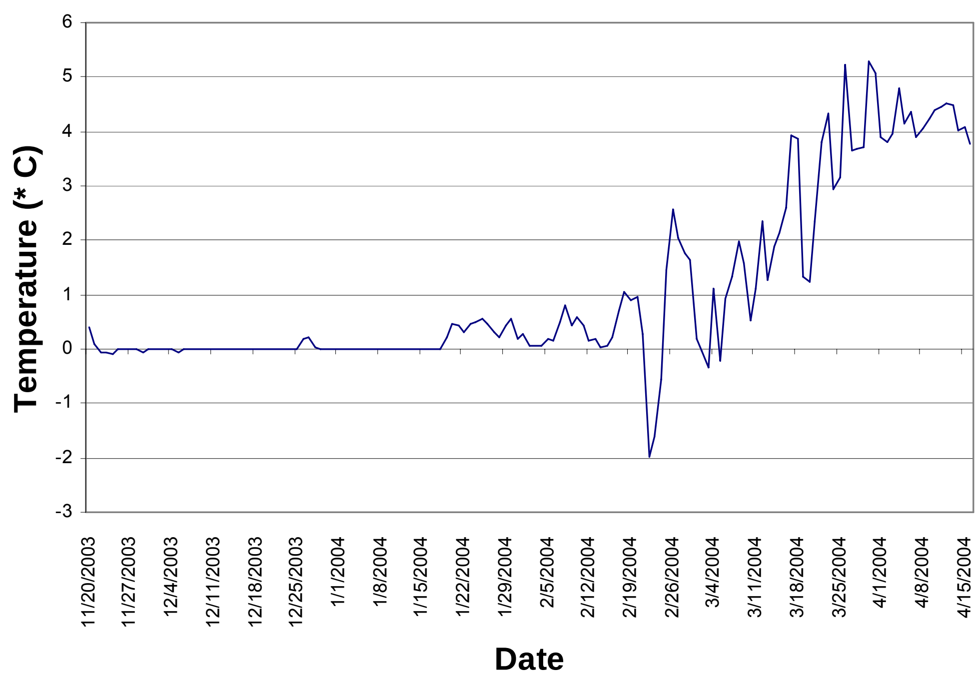

Figure 11. Upper Summit Creek (°C) mean daily temperature profile from November 20, 2003 through April 15, 2004.

Sampling Adult Burbot

Total Catch

Baited hoop nets were fished from November 6, 2003 through March 2004 for 1,965.1 net d or about 47,162.4 h. One hundred forty-two fish were caught representing nine different species of fish and 437 crayfish *Pacifastacus spp.* (Table 1). Catch per unit effort was 0.073 fish/net d for all species of fish (excluding crayfish). Northern pikeminnow *Ptychocheilus oregonensis* was the most abundant species comprising 44% of the total catch, 62 fish.

Hoop Net Catch of Burbot

Overall, 20 burbot (17 different fish) were captured in Idaho during the winter of 2003-2004, of which 19 were captured in this study and one in a companion study (Paragamian et al. in press) (Tables 1 and 2 and Figure 12). No burbot were captured in BC. Of the 19 total from this study, three were recaptures from this season while two were recaptures from previous years. Hoop net catch effort for burbot was 0.010 fish/net d or 103 net d/fish with most of the effort, 1,540 d of 1,965.1 d, in Idaho (Tables 1, 3, and 4 and Appendices 1, 2, and 3 for previous years).

We obtained length and weight measurements from 17 burbot (fish repeatedly captured over a short time period were excluded). Burbot ranged from 447 mm to 760 mm TL (mean = 634 mm, SD = 89 mm, n = 17) (Figure 12) and weighed from 420 g to 4,032 g (mean = 1,915 g, SD = 984, n = 17). Relative weight (W_r) ranged from 78 to 146 with a mean of 99.0 (SD = 19.1, SE = 4.6, n = 17). Burbot 214 (Table 2) was recaptured for the fourth time since 2000 with each capture near Ambush Rock (rkm 244.4-244.8). On the first capture March 10, 2000, it was 494 mm total length and weighed 600 g. It was recaptured twice in February 2001 (530 mm and 900 g), once in February 2002 (588 mm and 1,450 g), and the last recapture was January 26, 2004 (617 mm and 1,680 g).

Burbot Telemetry

Movement of 12 burbot was monitored by sonic telemetry during the 2003-2004 sampling season (Appendices 4 through 15). Eleven burbot were tagged with external sonic transmitters from November 26, 2003 through February 5, 2004 (Appendices 5 through 15), while an additional burbot had an internal sonic transmitter that had been active since 2001 (burbot 255, Appendix 4). Burbot 255 was first located in the fall of 2003 at rkm 154.8 in BC several km upstream of the confluence with the Goat River. Eight of the remaining 11 fish were tagged and released at Ambush Rock (rkm 244.5); two fish were tagged near rkm 173, close to the international border near the mouth of Boundary Creek (rkm 170); and one was tagged at about rkm 204.5. Biopsies were not performed to determine sex, but all burbot were believed to be adults. Fish 214 was known to be a male, because on two previous recaptures it released milt upon handling.

Eight burbot were tracked near the base of Ambush Rock (fish # 214, 238, 312, 314, 315, 316, 317, and 318). These fish were not captured in the same location but were found concentrated together in the same approximate position soon after tagging. These eight burbot were located at rkm 244.6 in January and 244.5 in February. At the time water temperature ranged from 1.7 to 3.5°C. Burbot 315 dropped downstream to rkm 239 during late January but returned to the group before mid February. Of these eight fish, five stayed through May at Ambush Rock with the exception of burbot 315 and 318, which moved downstream in early March whereas burbot 316 moved downstream during late March.

Two burbot were monitored further downstream of Ambush Rock near the Idaho BC border. Fish 310 moved from about rkm 173 in mid December and by late January was relocated downstream at rkm 140 near Summit Creek, BC, but was never relocated thereafter. Burbot 311 stayed near rkm 173 for several months, but in February, when the water temperature was about 3°C, moved to rkm 154.2 just above the Goat River. It was not relocated until May when it was found near the original capture site. The Goat River was searched by boat and from the banks for this burbot, as well as fish 255, but they were not found. However, it is possible these fish were further upstream in the Goat River.

Final telemetry locations for the season for individual fish were completed during July, August, and September 2004. By the end of June, it is believed that all short-term external transmitters had expired with the exception of burbot 255, which was relocated in a pool at about rkm 150.5 in June 2004.

Table 1. Hoop net catch by number, weight (g), and catch per unit effort (CPUE) for the Kootenai River and its tributaries in Idaho and BC, November 2003 through March 2004 with 1,965.1 d of effort (47,161.3 h of effort).

Species	**Number**	**Total Weight (g)**	**CPUE**[a]
Northern pikeminnow	62	24,430	0.032
Burbot	19	37,808	0.010
Sucker[b] *Catostomus catostomus* and *C. macrocheilus*	20	4,370	0.010
Peamouth chub *Mylocheilus caurinus*	2	282	0.001
White sturgeon *Acipenser transmontanus*	18	4,128	0.009
Bull trout *Salvelinus confluentus*	2	1,344	0.001
Yellow perch *Perca flavescens*	10	1,018	0.005
Black bullhead *Ameiurus melas*	2	100	0.001
Pumpkinseed *Lepomis gibbosus*	9	1,572	0.005
Crayfish	327	19,944	0.222
Total[c]	144	75,052	0.073

[a] A unit of effort is a single hoop net set for 24 hours.
[b] Includes longnose and largescale sucker.
[c] Crayfish excluded from total.

Table 2. Burbot identification number, location of capture, date of capture, and total length and weight.

Fish ID number	Location of capture (rkm)	Date of capture	Total length (mm)	Weight (g)
310	173.2	11/26/2003	633	1,450
311	173.1	12/7/2003	715	2,320
312	244.3	12/9/2003	729	2,560
313	204.5	12/15/2003	755	2,900
314	244.3	12/26/2003	703	3,528
312	244.5	12/29/2003	740	2,800
238	244.4	1/19/2004	571	1,138
214	244.4	1/26/2004	617	1,680
315	244.4	1/26/2004	582	1,680
316	244.4	2/5/2004	634	1,568
317	244.4	2/5/2004	720	2,884
318	244.4	2/5/2004	760	4,032
319[a]	170.0	2/9/2004	515	930
320	244.3	2/23/2004	550	980
316	244.3	2/27/2004	634	1,848
321	244.2	3/3/2004	646	1,540
321	244.4	3/5/2004	646	1,540
322	244.5	3/5/2004	560	1,120
323	244.5	3/5/2004	447	420
324	244.2	3/19/2004	650	1,820

[a] This burbot was captured in a companion tributary study (Paragamian et al. in press).

Table 3. Idaho Department of Fish and Game burbot hoop net captures and capture effort in three primary locations, October 2003-April 2004.

Sample year	River kilometer	Number of burbot captured	Total days	CPUE (fish/net days)
	120 to 152.9	0	377.8	0
Fall 2003–Spring 2004	153.0 to 169.9	0	47.0	0
	170 +	19	1,540.3	0.01234
Totals		19	1,965.1	0.00967

Table 4. Idaho Department of Fish and Game burbot hoop net captures and capture effort (burbot/hoop net day), of 1993-2004.

Sampling season	Number of burbot captures	Total net days	CPUE (fish/net day)
Mar 1993-May 1993	17	554.2	0.031
Oct 1993-April 1994	8	909.8	0.009
Nov 1994-Feb 1995	33	688.8	0.048
Nov 1995-Mar 1996	28	495.8	0.056
Oct 1996-Mar 1997	23	1,061.1	0.022
Oct 1997-May 1998	42	1,240.9	0.034
Oct 1998-April 1999	44	1,453.7	0.030
Oct 1999-April 2000	36	1,712.9	0.021
Oct 2000-Mar 2001	73	2,085.2	0.035
Oct 2001-April 2002	17	1,529.9	0.011
Oct 2002-Mar 2003	11	1,809.7	0.006
Nov 2003- Mar 2004	19	1,965.1	0.010
Totals	351	15,507.16	
Mean			0.023

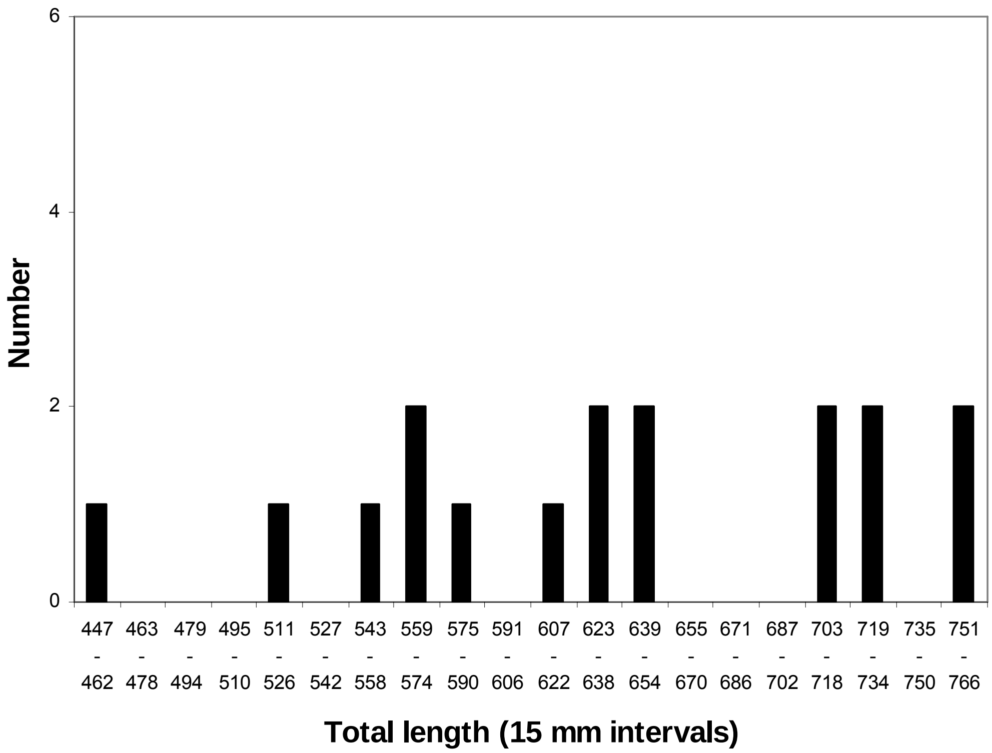

Figure 12. Length frequency distribution of burbot (n = 17) caught by baited hoop nets (includes a burbot caught in a companion study), excluding recaptures, Kootenai River, Idaho and BC from October 2003 through March 2004.

Larval Sampling

Larval Sampling Tows—Total towing time was 745 minutes or 12.4 hours. The nets filtered a total water volume of 25,277 m^3. No larval burbot were captured, although three mountain whitefish *Prosopium williamsoni* larva were caught.

Light Traps—Three hundred seven juvenile and larval fish were captured but no burbot.

DISCUSSION

<u>Low Discharge and Burbot Spawning Location</u>

The operation of Libby Dam for winter hydropower production and flood control has been cited as one of the major factors contributing to the decline of burbot in the Kootenai River (Paragamian 2000). Although discharges were relatively low during the winter of 2003-2004 compared to previous post-Libby Dam years (Figure 4), there were several rapid increases in discharge for brief periods, and discharges in general exceeded the KVRI discharge SOR. These rapid increases may have affected migrating burbot but did not appear to affect burbot at Ambush Rock once their spawning group was established. Eight burbot were monitored near this location from January through February 2004. The highest discharge during the burbot migration period occurred between November 19 and December 18, 2003, when discharge increased rapidly from about 170 to 592 m^3/s and remained high (Figure 4). But during the spawning period it increased again, at a plateau of 283 m^3/s for 15 d, and was increased again to 325 m^3/s. By mid January, it was decreased to about 113 m^3/s. During this period, no significant movement of burbot out of the Ambush Rock reach was observed.

The Ambush Rock reach near Bonners Ferry appears to be a second spawning location for burbot, with the Goat River as the other. Although many burbot have been captured at Ambush Rock, it was not until winter of 2000-2001, when low discharge prevailed, that it appeared to be a mainstem spawning location (Kozfkay and Paragamian 2002). A few gravid burbot were also captured in following years, which provided further evidence to suggest this reach was a spawning location (Gunderman and Paragamian 2003; Paragamian and Hoyle 2005). Telemetry data from eight burbot tracked during the winter of 2003-2004 suggested burbot were all closely associated with one another for most of January and part of February, during the time when spawning occurs. Since the winter of 2000-2001, in general, discharges have been low (Kozfkay and Paragamian 2002; Gunderman and Paragamian 2003; Paragamian and Hoyle 2005) compared to the previous winters of study (Paragamian 2000). Presumably, the low precipitation and snow pack during the latter winters have been responsible for the USACE and BPA to release more than a minimum discharge of 113 m^3/s from Libby Dam less frequently for most of the winter. This factor, and cooperation with the Burbot Recovery Subcommittee of KVRI, allowed burbot to migrate and behave much as they may have prior to the construction and operation of Libby Dam. The results served to confirm our previous findings that in the absence of high discharges (>about 340 m^3/s), burbot distributed themselves more extensively during the spawning period and are believed to have spawned at least in 2000-2001 (Kozfkay and Paragamian 2002) and likely during the following winters. However, with the exception of the capture of several small burbot believed to be from the 2001 year class (Paragamian and Hoyle 2005), we have no evidence to support mainstem recruitment in the past years.

Burbot Population Trends and Index Sites

In the possible event that a Memorandum of Understanding and a Conservation Agreement between river managers is adopted, it will be important to have established population trend indices with index sampling sites for burbot. Population trend indices can be tailored to provide performance standards or measures. A performance standard can be a specific numerical objective or goal. The rate of the population change to the objective could be interpreted as a measure of improvement.

One of the most important criteria to measure burbot population performance standards would be the establishment of sampling index sites and an established sampling season in the event time or funding is limited. This would allow more accurate inferences to be made on the small population. However, in the event there is an expansion of the burbot population and funding is available, a more inclusive sample survey design may be applied (Scheaffer et al. 1979) and allow comparisons to data collections prior to 2004. For example, from 1993 through 2004, hoop net effort (Table 4 and Appendix 1) was expended within every tenth of an rkm reach in the Kootenai River from rkm 123 through rkm 244.6 (Table 3 and Appendices 2 and 3). Sampling season varied slightly but was usually from October through April each year. Although there is some bias to site sampling due to the success in capturing burbot at specific locations, the site-specific CPUE information by tenth of an rkm suggests three and possibly four reaches can be used as index locations for burbot population trend information (Appendix 3). They are Nicks Island (rkm 144.4-144.6), the mouth of Corn Creek (rkm 150.2) to the mouth of the Goat River (rkm 152.7), the Goat River, and Ambush Rock (rkm 244.4–244.6) (Appendix 3). Tributary index locations for burbot sampling should include Deep and Boundary creeks (Paragamian et al., in press. Sampling season should remain the same because the prespawn and spawning periods are the times of greatest activity (Breeser et al. 1988; McPhail and Paragamian 2000; Pääkkönen et al. 2000).

An annual estimate of population numbers along with length-frequencies, abundance, and weight indices would also be important measures to describe burbot population trends (see Chapter 2 Pyper et al.). The open Seber-Jolly population estimate model (Ricker 1975; Seber 1982, Pine et al. 2003) and the POPAN-5 analysis software (Arnason et al. 1998a, 1998b) has been used in the past to estimate burbot population numbers in the Kootenai River. This model is based on multiple mark-recapture data over a series of years. To project the possible time to extinction, a death-only model that assumes no births or new entries can be fit based on observations of an extended interval of little or no significant natural recruitment. Population biomass can be estimated from abundance, year-specific length composition, and average length-specific weight. Also, because proportional stock density (PSD) and relative weight ($W_{r)}$) (Fisher et al. 1996) have been found to be useful population size structure and condition tools for burbot, they too should be incorporated in an overall annual population assessment scheme. For example, relative weight of burbot in the Kootenai River has remained in the high 90s, mean in 2003-2004 of 99, in comparison to the management target of 80 ± 5 for river populations recommended by Fisher et al. (1996).

Total catch per unit effort (CPUE) has been used to compare burbot stock densities (Parker et al. 1988) and would be a suitable population trend index as well as helping to determine the effectiveness of rehabilitation efforts. Our total number of captures of 19 burbot in 2003-2004 was more than that of the previous season (one burbot/165 net d) but the CPUE was one burbot/95.7 net d, only half of the 12 year average of one burbot/45 net d. During the winter of 2000-2001, CPUE was one fish/29 net d. For comparison, CPUE of burbot in four Alaskan lakes ranged from one fish/two net d to three fish/one net d (Parker et al. 1988), while in the Tanana and Chena rivers CPUE was >one fish/one net d and one fish/two net d, respectively (Evenson 1993). Based on these comparisons, the densities of burbot in exploited Alaskan fisheries appear to be 20 times greater, at a minimum, than the Kootenai River population.

Temperature Changes in the Kootenai River

Prior to Libby Dam, winter water temperatures of the Kootenai River progressively warmed as it passed from the upper reaches in BC and Montana to the meandering reach in Idaho (Appendix 16). Historical (pre-dam) winter water temperatures were all within the temperatures most frequently published for burbot spawning, 1-4°C (Becker 1983; McPhail and Paragamian 2000). However, post-Libby Dam water temperatures are now warmer as they are released through Libby Dam (3-7°C) and cool as the water travels to the meandering reach in Idaho, as it did during the winter of 2003-2004 (Figure 4 and Appendix 16). Yet water temperatures in the Kootenai River are now 2-3°C warmer than pre-Libby Dam (Partridge 1983) and at times may be too warm for burbot spawning. Warmer water temperatures from Truman Dam in Missouri are thought to have inhibited walleye *Sander vitreus* spawning in the Gasconade River (DiStefano et al. 1997).

The importance of post-Libby Dam water temperature and burbot spawning is an unresolved question regarding burbot decline. Discharge and temperature conditions (generally low discharges and cold temperatures) in 2003-2004 may have provided sufficiently cold conditions for burbot to spawn, based on the close proximity of eight telemetered fish and cold temperatures of 1.7 to 4.0°C. Contrary to this, temperature records of winters of 2001-2002 (Gunderman and Paragamian 2003) and 2002-2003 (Paragamian and Hoyle 2005) were warmer despite low discharges. As a result, the limited movement of burbot in November through early January of those years may have been influenced by the warmer winter water temperatures. Mean daily water temperature in the Kootenai River during the winter of 2002-2003 ranged from 1-8°C from November through mid February. In 1999-2000 (Paragamian et al. 2001), discharges and temperatures were also high. Mean daily water temperature in the Kootenai River ranged from a maximum of 12.4°C on October 9, 1999 to a minimum of 2.4°C on February 22, 2000. There was no evidence of spawning that winter. For comparison, temperatures in the Goat River where burbot are known to spawn each year were much cooler, ranging from about 0-2°C during December and January. Water temperature at the same time period during the winter of 2000-2001 when burbot spawned was also cooler, ranging from 0-4°C, and burbot were thought to be more active earlier in that season. Preliminary study suggests river temperatures in the Kootenai River must decrease in winter to a range of about 3-4°C to motivate burbot to initiate a spawning migration (Paragamian, in progress). Our understanding could be further enhanced with a well-designed laboratory study of the effects of temperature on burbot movement and reproductive hormones (plasma steroids).

RECOMMENDATIONS

1. Establish an index monitoring scheme to measure changes in population numbers (Seber-Jolly population estimate), size structure (PSD), condition W_r, and an index of abundance (CPUE) that is based on three to four site specific sampling reaches while the population is low.

2. I recommend a burbot prespawning migration and spawning discharge from Libby Dam ranging from 113-300 m^3/s and averaging 176 m^3/s for a minimum of 90 d, beginning November 15, 2004 and extending through February 15, 2005. Burbot spawning migration (arrival time) and evidence of spawning (spent burbot, eggs, and larvae) should be monitored at Ambush Rock to test the null hypothesis that burbot migration is not different than previous years (1996, 1997, 1998, and 1999) of high discharges.

3. Determine, under laboratory conditions, the effect of high velocities (>25 cm/s) and elevated winter temperatures on reproductive hormones and vitellogenin synthesis and the release of gonadotropin for egg ovulation and blood chemistry.

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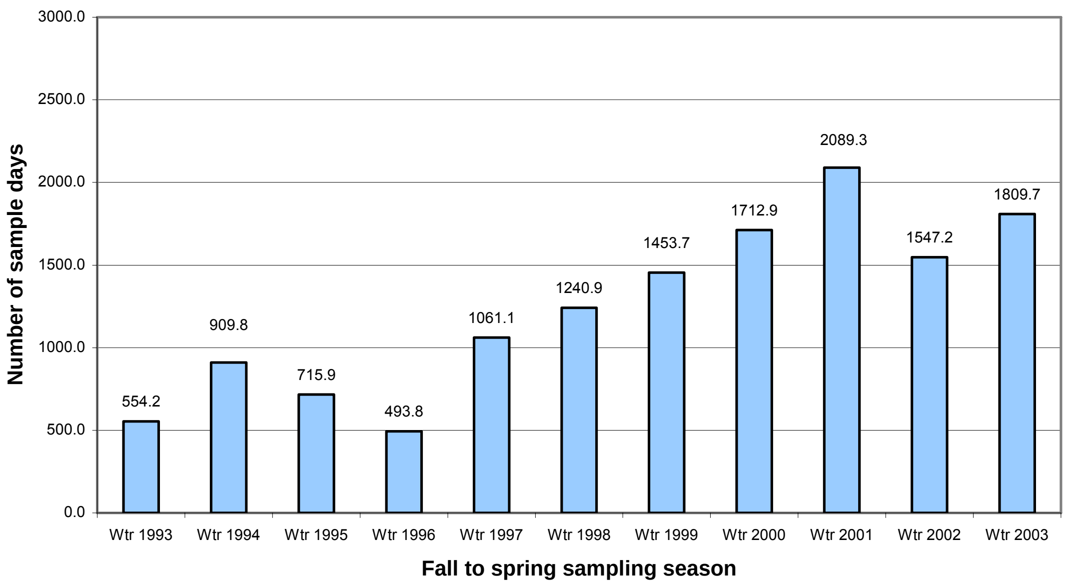
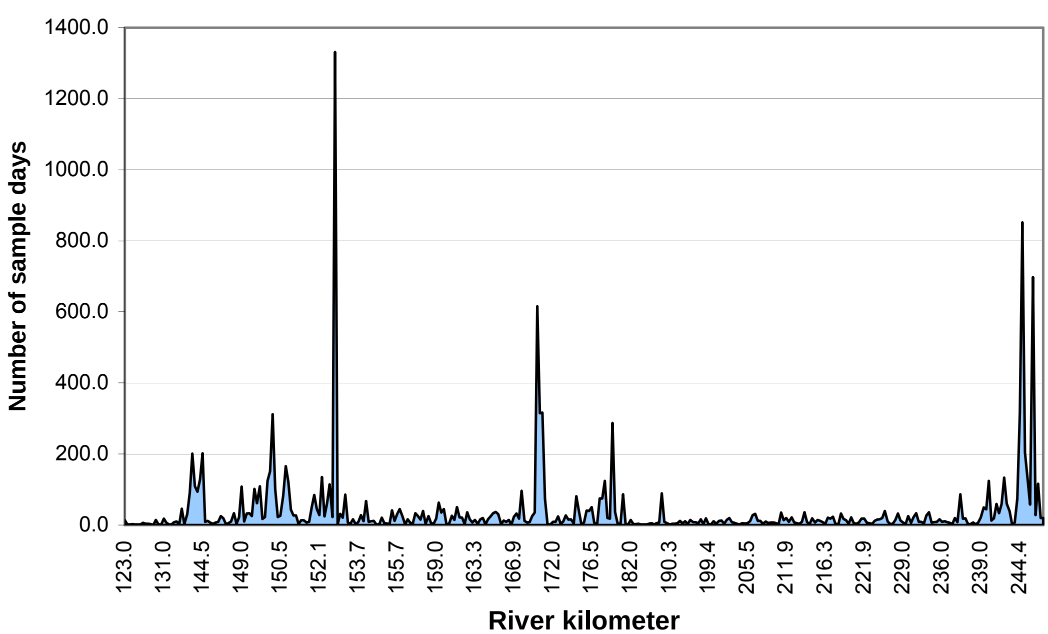
APPENDICES

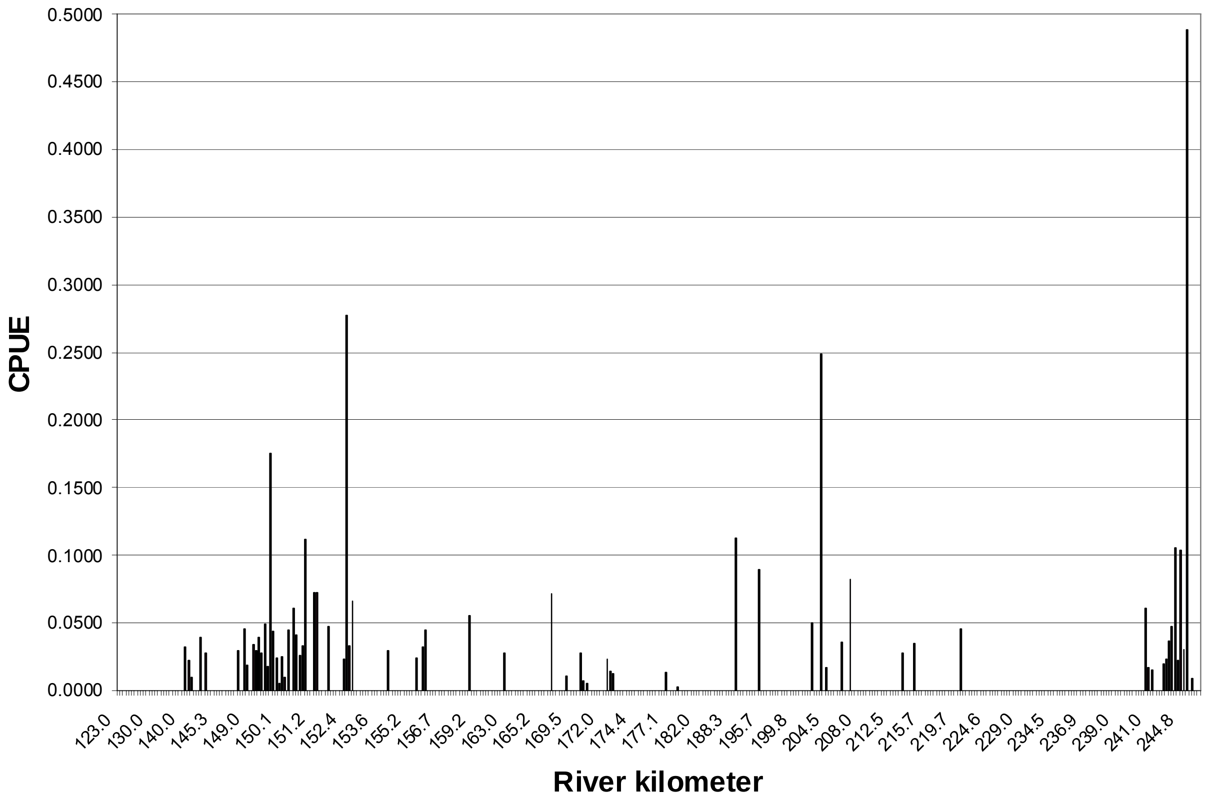
Appendix 1. Total hoop net sampling effort by year (1993-2003) for the Kootenai River in Idaho and British Columbia.



Appendix 2. Days of sampling effort by river kilometer for all seasons, 1993-2003, Kootenai River in Idaho and British Columbia.



Appendix 3. Catch per unit effort (CPUE) for burbot from 1993 through 2004 from rkm 123 in British Columbia to rkm 244.6 at Ambush Rock Idaho. One unit of effort is a 24 h hoop net set. Note: only one burbot was captured above rkm 244.6 at about rkm 260, there was a total of 186 d of hoop net effort above rkm 244.6 in 1993.



Appendix 4. Location, date, water temperature, and depth of burbot 255 (sonic 7254) as determined by sonic telemetry and depth sounder. This burbot was tagged in October of 2001.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
10/26/01	150.8	22.6	9.0
10/29/01	150.8		8.5
11/7/01	151.4	13.1	
11/19/01	167.2	11.6	8.0
11/28/01	169.5	13.4	6.0
12/4/01	167.0		
12/11/01	150.5		
12/20/01	153.2	11.6	4.5
12/28/01	152.9		4.0
1/2/02	153.0		
1/8/02	153.2		
1/25/02	157.0		
2/5/02	157.2	16.8	4.0
2/22/02	152.6	8.2	4.0
3/8/02	152.7	11.6	1.5
9/18/02	154.0	15.9	16.0
1/11/2003	154.8	13.72	3.0
1/14/2003	154.0	17.98	
1/15/2003	154.8	19.05	3.0
1/16/2003	154.8	18.44	3.0
1/17/2003	159.4		
1/18/2003	161.2	18.29	2.0
1/21/2003	154.9	18.14	
1/22/2003	154.9	11.28	
1/28/2003	150.7	19.51	4.0
1/30/2003	154.7	16.00	
1/31/2003	152.0	8.53	
2/1/2003	153.3	10.52	4.0
2/4/2003	151.9		
2/6/2003	152.7		
2/7/2003	151.1	14.02	3.0
2/8/2003	152.7	13.11	3.0
2/11/2003	152.2	8.53	3.0
2/13/2003	152.2	7.32	
2/14/2003	152.7	6.71	
2/15/2003	152.7	4.88	3.0
2/18/2003	152.7	2.44	
2/20/2003	152.7	10.06	4.0
2/22/2003	152.7	12.19	
2/26/2003	152.7	8.38	1.5
2/28/2003	152.7	12.19	
4/23/2003	150.7		
4/25/2003	150.8	18.75	
3/2/2004	150.5	17.37	
6/24/04	150.5	15.2	

Appendix 5. Location, date, water temperature, and depth of burbot 214 (sonic 2673) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
1/26/2004	244.4	17.68	3.0
1/27/2004	244.4		
1/29/2004	244.6	18.90	3.5
2/3/2004	244.6	19.81	2.7
2/10/2004	244.5	21.34	
2/12/2004	244.5		3.0
2/17/2004	244.5	20.73	
2/19/2004	244.5	20.73	3.0
2/20/2004	244.5	20.73	3.0
5/27/2004	244.5		

Appendix 6. Location, date, water temperature, and depth of burbot 238 (sonic 1-2) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
1/19/2004	244.4	15.85	3.5
1/20/2004	244.4		
1/22/2004	244.5	18.59	2.0
2/3/2004	244.6	19.81	2.7
2/10/2004	244.5	21.34	3.0
2/12/2004	244.5		3.0
2/17/2004	244.5	21.34	
2/24/2004	244.5	19.20	
2/25/2004	244.6	24.08	3.5
2/27/2004	244.5	16.76	3.5
3/3/2004	244.6	17.98	4.0
3/23/2004	244.5	18.90	5.0
3/24/2004	244.5	18.90	
3/25/2004	244.5	12.80	5.0
3/31/2004	244.5	19.20	6.0
4/14/2004	244.5	11.28	7.5
4/20/2004	244.5	21.34	8.0
4/26/2004	244.5	11.58	7.0
5/10/2004	244.5	6.10	
5/27/2004	244.5		
6/1/2004	244.5		
6/7/2004	244.5	15.85	

Appendix 7. Location, date, water temperature, and depth of burbot 310 (sonic 238) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
11/26/2003	173.2	31.39	5
11/27/2003	173.2		
11/28/2003	173.2	30.48	4.7
12/7/2003	173.3	22.25	5.5
12/11/2003	165.9	16.46	5
12/16/2003	165.5	21.34	4.8
12/18/2003	165.4	20.12	5
12/19/2003	165.4	21.34	5
12/22/2003	164.6	19.20	4.5
12/23/2003	164.6	16.76	4.5
12/24/2003	164.6	18.90	4.5
12/29/2003	164.6	23.16	2.7
12/30/2003	164.6	19.20	3
12/31/2003	164.6	19.81	2.7
1/12/2004	161.5		3.5
1/13/2004	164.4	14.33	3.5
1/14/2004	156.5		3.5
1/15/2004	159.0	14.33	3.5
1/22/2004	140.0	28.96	2
1/26/2004	140.0	27.43	3
1/28/2004	140.0	21.64	3.5
1/30/2004	140.0	24.38	3
2/2/2004	140.0	23.77	3

Appendix 8. Location, date, water temperature, and depth of burbot 311 (sonic 2237) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
12/7/2003	173.1	27.43	5.5
12/9/2003	173.1		
12/10/2003	173.4	30.48	5
12/11/2003	173.3	20.12	5
12/15/2003	173.2	30.48	4.8
12/16/2003	172.4	21.95	4.8
12/18/2003	172.5	12.80	5
12/19/2003	172.5	15.85	5
12/22/2003	172.5	11.88	4.5
12/24/2003	173.4	29.26	4.5
12/29/2003	173.4	24.69	2.7
12/30/2003	173.4	27.73	3
12/31/2003	173.4	27.7	2.7
1/12/2004	173.0		3.5
1/13/2004	173.2	21.33	3.5
1/14/2004	173.0		3.5
1/15/2004	173.1	18.28	3.5
1/20/2004	173.1	22.55	3
1/21/2004	173.4	11.58	2
1/22/2004	173.3	21.03	2
1/26/2004	173.2	24.68	3
1/27/2004	173.1	22.55	3.5
1/28/2004	173.1	21.94	3.5
1/30/2004	164.9	23.77	3
2/2/2004	164.9	20.72	3
2/4/2004	163.5	10.97	2.7
2/5/2004	163.5	12.19	
2/11/2004	154.2		3
5/10/2004	172.0	7.92	
6/2/2004	172.8	9.14	8
6/9/2004	172.8	11.27	8.5

Appendix 9. Location, date, water temperature, and depth of burbot 312 (sonic 2335) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
12/9/2003	244.3	16.76	5.5
12/10/2003	244.3		
12/12/2003	244.6	21.95	5
12/16/2003	244.6	21.95	4.8
12/18/2003	244.6	20.73	5
12/19/2003	244.6	22.25	5
12/22/2003	244.6	19.812	4.5
12/24/2003	244.6	20.42	4.5
12/29/2003	244.5	19.81	2.7
12/30/2003	244.6		
1/8/2004	244.5	20.12	1.5
1/11/2004	244.6	20.42	
1/13/2004	244.6	19.20	3.5
1/15/2004	244.6	19.20	3.5
1/20/2004	244.5	18.89	3
1/22/2004	244.6	15.24	2
1/26/2004	244.6	20.11	3
1/27/2004	244.5	17.98	3.5
1/29/2004	244.6	18.89	3.5
1/30/2004	244.6	19.50	3
2/3/2004	244.6	19.812	2.7
2/6/2004	244.5		3
2/10/2004	244.5	21.33	3
3/11/2004	219.5	12.192	
3/23/2004	219.4	14.32	5
3/25/2004	219.5	9.44	5
4/7/2004	219.5	6.70	6.5
4/26/2004	219.5	11.27	7
5/3/2004	219.5	15.24	10
5/10/2004	219.5	13.10	
6/1/2004		18.89	
6/7/2004	219.0	15.24	

Appendix 10. Location, date, water temperature, and depth of burbot 313 (sonic 2326) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
12/15/2003	204.5	22.86	5
12/16/2003	204.5	2.44	4.8
12/18/2003	203.3	12.19	5
12/19/2003	205.0	15.85	5
12/22/2003	205.0	21.03	4.5
12/24/2003	205.0	14.94	4.5
12/30/2003	195.7	23.77	3
12/31/2003	195.7	21.64	2.7
1/8/2004	195.7	18.89	1.5
1/13/2004	192.0	17.67	3.5
1/15/2004	188.3	18.28	3.5
1/20/2004	182.0	10.97	3
1/21/2004	177.0	14.02	2
1/22/2004	174.2	11.28	2
1/30/2004	155.6	14.02	3
2/5/2004	146.7	9.14	

Appendix 11. Location, date, water temperature, and depth of burbot 314 (sonic 2345) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water Temperature (°C)
12/26/2003	244.3	16.76	4
12/27/2003	244.3		
12/29/2003	244.4	24.08	2.7
12/30/2003	244.5	18.29	3
1/8/2004	244.5	18.90	1.5
1/11/2004	244.6	21.33	
1/13/2004	244.6	15.24	3.5
1/15/2004	244.6	15.24	3.5
1/20/2004	244.5	19.50	3
1/22/2004	244.5	20.12	2
1/26/2004	244.5	18.59	3
1/27/2004	244.5	17.98	3.5
1/29/2004	244.6	18.90	3.5
1/30/2004	244.6	19.51	3
2/3/2004	244.6	19.81	2.7
2/6/2004	244.5		3
2/10/2004	244.5	21.34	3
2/12/2004	244.5		3
2/18/2004	244.5	21.34	3
2/19/2004	244.5	20.73	3
2/20/2004	244.5	20.73	3
2/23/2004	244.5	19.20	3.5
2/25/2004	244.5	12.19	3.5
2/27/2004	244.5	16.76	3.5
3/3/2004	244.6	17.98	4
3/4/2004	244.6	17.98	4
3/5/2004	244.6	20.12	4
3/11/2004	244.6	22.25	
3/23/2004	244.5	18.90	5
3/24/2004	244.5	18.90	
3/25/2004	244.5	12.80	5
3/31/2004	244.5	19.20	6
4/7/2004	244.5	17.37	6.5
4/14/2004	244.5	11.28	7.5
4/20/2004	244.5	21.34	8
4/26/2004	244.5	11.58	7
5/3/2004	244.5	7.62	10
5/27/2004	244.5		

Appendix 12. Location, date, water temperature, and depth of burbot 315 (sonic 2425) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water temperature (°C)
1/26/2004	244.4	17.68	3
1/27/2004	244.4		
2/6/2004	239.0		3
2/10/2004	239.0	7.62	
2/17/2004	244.5	21.34	3
2/19/2004	244.5	20.73	3
2/20/2004	244.5	20.73	3
2/23/2004	244.5	19.20	3.5
2/25/2004	241.2	6.10	
2/27/2004	244.5	16.76	3.5

Appendix 13. Location, date, water temperature, and depth of burbot 316 (sonic 2354) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water temperature (C)
2/5/2004	244.4	18.90	2.7
2/6/2004	244.4		
2/10/2004	244.5	21.34	
2/12/2004	244.5		3
2/17/2004	244.5	21.34	
2/19/2004	244.5	20.73	3
2/20/2004	244.5	20.73	3
2/23/2004	244.6	23.1648	3.5
2/25/2004	244.5	12.192	
2/27/2004	244.3	16.1544	3.5
3/3/2004	244.6	17.98	4
3/4/2004	244.6	17.98	4
3/5/2004	244.6	20.12	4
3/23/2004	227.5	13.72	5
3/25/2004	227.5		
4/14/2004	227.3	18.29	7.5
4/20/2004	227.3	18.288	8
4/26/2004	227.4	17.6784	7
5/3/2004	227.2	17.9832	10
6/1/2004	227.0	9.4488	
6/7/2004	227.0	8.2296	

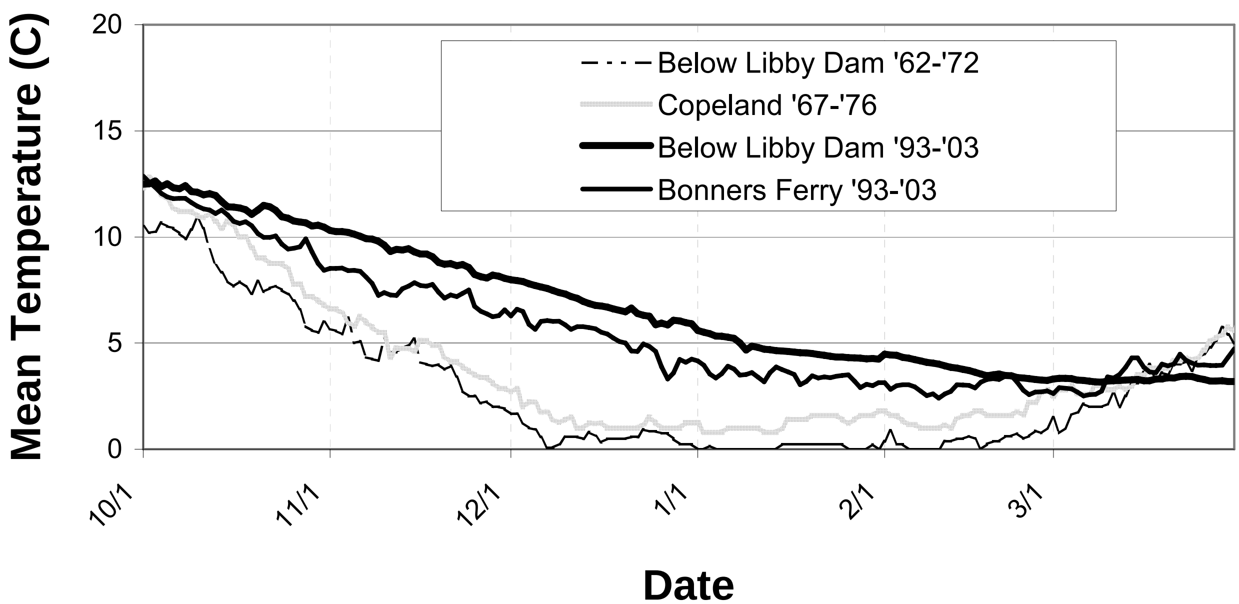
Appendix 14. Location, date, water temperature, and depth of burbot 317 (sonic 223) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water temperature (C)
2/5/2004	244.4	18.90	2.7
2/6/2004	244.4		

Appendix 15. Location, date, water temperature, and depth of burbot 318 (sonic 2873) as determined by sonic telemetry and depth sounder.

Date	Location (rkm)	Depth (m)	Water temperature (C)
2/5/2004	244.4	18.90	2.7
2/6/2004	244.4		
2/10/2004	244.5		
2/25/2004	244.5	4.57	3.5
3/4/2004	227.4	21.34	4
3/11/2004	224.6		
4/7/2004	225.0	10.06	6.5
4/14/2004	225.0	18.59	7.5
4/26/2004	225.0	19.81	7
5/3/2004	225.0	10.06	10
5/10/2004	224.4	4.88	
6/1/2004	225.5	5.79	

Appendix 16. Kootenai River water temperatures pre- and post-Libby Dam, below Libby Dam (Jennings, Montana), Bonners Ferry, and Copeland, Idaho.



CHAPTER 2—STATUS AND POPULATION DYNAMICS OF BURBOT IN THE KOOTENAI RIVER, IDAHO AND BRITISH COLUMBIA, CANADA

ABSTRACT

We examined the status and population characteristics of Kootenai River burbot *Lota lota* using capture-recapture data from 1993-2004. Our objective was to determine the time remaining before this population becomes functionally extinct and to help guide conservation efforts. A total of 403 burbot were captured from 1993 through 2004 (primarily with baited hoop nets), of which 300 were tagged and released, 31 were not tagged, and 72 were recaptures of fish tagged up to four years prior. Hoop net catch per unit of effort (CPUE) decline precipitously from 0.054 CPUE in 1996 to 0.008 CPUE in 2004. Mean burbot length increased about 8 mm/yr from 516 mm in 1993 to 629 mm in 2004. Two models were developed for capture-recapture analysis, one that included effort data through a series of river reaches and one without effort data. The effort model appeared to be more reliable and suggested an average annual mortality of 63%, an average annual recruitment of 77 fish, and an average estimate of 148 burbot in the Kootenai River from 1996 through 2004. Average declines in recruitment and population abundance were estimated to be 21% and 14% per year, respectively, resulting in estimates of only 20 recruits and a population size of only 50 burbot in 2004. These data confirm that Kootenai River burbot are in serious decline and may already have passed the point of functional extinction where the population could not be expected to recover if favorable habitat conditions were restored.

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INTRODUCTION

The Kootenai River is at the northern edge of Idaho in the continental United States and southern British Columbia (BC), Canada but near the southern edge of the circumpolar distribution of the burbot *Lota lota* (McPhail and Lindsey 1970). Although burbot are globally widespread and abundant throughout much of their historical range (Muth and Smith 1974; Bruesewitz 1990; Evenson and Hansen 1991; Edsall et al. 1993; Maitland and Lyle 1996; Arndt and Hutchinson 2000), the Kootenai population appears to be in serious decline (Paragamian et al. 2000). Popular burbot fisheries in Kootenay Lake and the Kootenai River had collapsed by the 1970s (Paragamian et al. 2000). Neither population has recovered despite closure of the fisheries (Paragamian et al. 2000). Extensive alteration of the Kootenai ecosystem may have shifted habitat conditions past the margin of suitability for burbot. It is unclear whether significant numbers are still present and whether recovery by the remaining stock is feasible.

Lake, river, and tributary spawning life histories were historically represented among Kootenai River burbot, but all population elements appear to have failed. Small numbers remain in the Duncan River at the north end of Kootenay Lake, but burbot are now rarely observed in the South or West arms of Kootenay Lake or the Kootenai River between the lake and Kootenai Falls. Burbot remain common in the upper Kootenai system upstream from Kootenai Falls including Libby Reservoir and the upper river. Kootenai burbot were petitioned for listing as threatened under the U.S. Endangered Species, but the U.S. Fish and Wildlife Service found in 2003 that listing was not warranted because this population does not represent a distinct population segment. Burbot in the lower Kootenai River and Kootenay Lake of Idaho and British Columbia are genetically different from burbot stocks in Montana upstream of Kootenai Falls (Paragamian et al. 1999), but the difference was not deemed sufficient to warrant formal protection.

Burbot represent a significant historical and cultural resource to the local region and are subject of a regional Burbot Conservation Strategy developed by local stakeholders (KVRI Burbot Committee 2005). Burbot have been subject to extensive sampling efforts in the Kootenai River over the last decade, and this information is critical for the development of effective conservation and recovery measures. This paper synthesizes results of this long-term sampling program to determine current population trend, abundance, and demographic characteristics.

OBJECTIVE

Because burbot in the Kootenai River may be at risk of demographic extinction (Paragamian 2000), a Conservation Strategy (Anonymous 2002) was prepared to outline measures necessary to rehabilitate the population. This demographic evaluation was prepared because current numbers and survival rates of burbot in the Kootenai River are necessary to determine the population course and the time remaining before this population becomes functionally extinct. Back-calculated year-class strength can help identify conditions suitable for successful recruitment. Expected numbers of mature spawners affect the likelihood of natural spawning if suitable conditions can be restored, as well as forecast for capture and recapture of fish. Assessments of the burbot population status and population dynamics will help guide conservation efforts.

METHODS

Study Area

The Kootenai River (spelled Kootenay for Canadian waters) is one of the largest tributaries to the Columbia River. Originating in Kootenay National Park, BC, the river flows south into Montana, where Libby Dam impounds water into Canada and forms Lake Koocanusa (Figure 13). From Libby Dam, the river flows west and then northwest into Idaho, then north into BC and Kootenay Lake. The Kootenai River at Porthill, Idaho (i.e. at BC border), drains about 35,490 km^2; the reach in Idaho is 106 km long. Kootenay Lake drains out the West Arm and eventually the river joins the Columbia River near Castlegar, BC.

The Idaho reach is characterized by three different channel types: steep canyon walls and a high gradient (~0.6 m/km) typify the corridor from the Montana Border to the Moyie River. About 1 km below the Moyie River downstream to Bonners Ferry, the river follows a braided channel. Downstream of Bonners Ferry, the river meanders through a broad floodplain with a lower gradient of about 0.02 m/km. Tributary streams of the Kootenai River are typically high gradient as they pass through mountain canyons but revert to lower gradients when they reach the valley floor.

Adult Sampling

The Kootenai River Fisheries Investigation was initiated in 1993 by the Idaho Department of Fish and Game (IDFG) to document burbot abundance, distribution, size structure, reproductive success, and movement, and to identify factors limiting burbot in the Kootenai River. Sampling continued annually through the spring of 2004. Adult burbot were sampled using baited hoop nets primarily during the winter season to coincide with seasonal migrations. Hoop nets had a maximum diameter of 0.61 m (see Bernard et al. 1991; Paragamian 1995 for a description of the nets and the method of deployment). Although sampling dates varied annually, sampling seasons generally began in the fall and continued through the following spring (Table 5). Catch per unit of effort (CPUE) was measured by a 24 h set period for each net, with one net day equaling one unit of effort.

Nets were deployed in deep areas (usually the thalweg) of the Kootenai River between rkm 123 (South Arm of Kootenay Lake) and rkm 270 (upstream of the Moyie River), although effort during most years was concentrated around Ambush Rock (rkm 244) near Bonners Ferry, Idaho; Boundary Creek near Porthill, Idaho (rkm 170); and the Goat River, near Creston, BC (rkm 152).

Table 5. Start and end dates for the winter sampling season, 1993-2004.

Sampling Season	Start Date	End Date
Wtr 1993	March 1993	May 1993
Wtr 1994	October 1993	April 1994
Wtr 1995	November 1994	February 1995
Wtr 1996	November 1995	March 1996
Wtr 1997	October 1996	March 1997
Wtr 1998	October 1997	May 1998
Wtr 1999	October 1998	April 1999
Wtr 2000	October 1999	April 2000
Wtr 2001	October 2000	March 2001
Wtr 2002	October 2001	April 2002
Wtr 2003	October 2002	March 2003
Wtr 2004	November 2003	March 2004

Nets were usually lifted on Monday, Wednesday, and Friday of each week. Fish captured in hoop nets were identified by species, enumerated, measured for total length (TL), and weighed to the nearest gram (g). Sex of most burbot was determined by a gentle abdominal massage, and the vent was examined for sex products. Some post-spawn fish were also biopsied to determine sex and reproductive status. Most burbot were implanted with a passive integrated transponder (PIT) tag in the left opercular muscle, and a small piece of pelvic fin tissue was collected for genetic analysis and archiving (Paragamian 1999). Burbot not implanted with a PIT tag included those that died during capture or burbot captured during other sampling efforts when the appropriate tagging gear was not present.

In addition to adult burbot sampling efforts by the IDFG, Kootenai River burbot have been targeted by the Montana Department of Fish, Wildlife and Parks (1998 only) as well as the British Columbia Ministry of Water, Land and Air Protection (BCMWLAP; 1996-1999 and 2001-2002; Table 6). Further, Kootenai River burbot have been incidentally caught during summer sturgeon sampling in the Kootenai River.

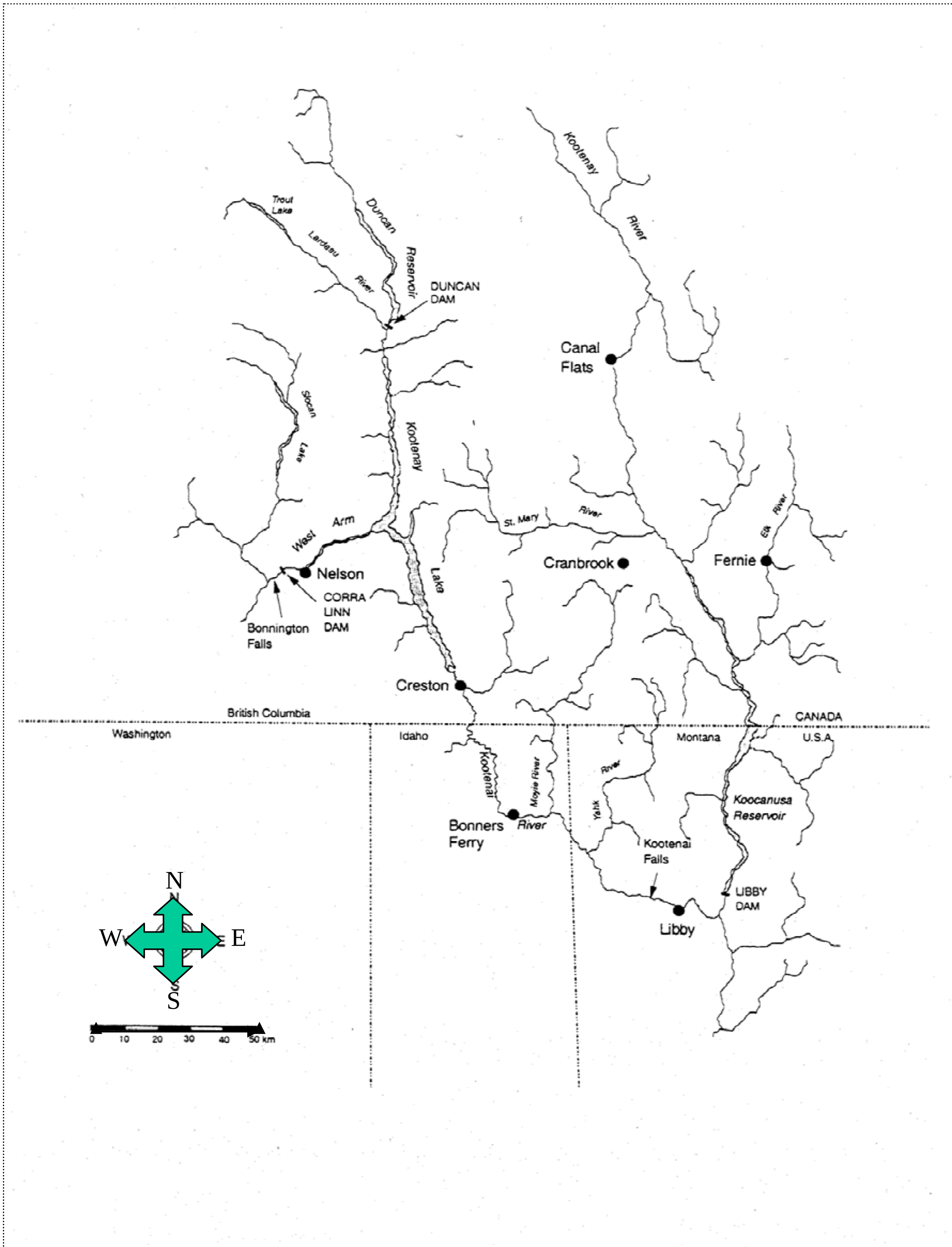

Figure 13. Location of Kootenay Lake, the Kootenai River, Lake Koocanusa, and major tributaries in the basin; river kilometer measurements are from the northernmost arm of Kootenay Lake.

Table 6. Summary of adult burbot effort (net days), by location, gear, and year.

Agency	Target Species	Location	Gear	Season	Year 1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
IDFG	Burbot	Kootenai River	Hoopnets	Winter	554	910	689	496	1,061	1,241	1,454	1,713	2,085	1,530	1,810	1,965	15,507
	Sturgeon	Kootenai River	Hoopnets, Set Lines	Summer	?	?	?	?	?	?	?	?	?	?	?	?	?
BCMELP	Burbot	Kootenay Lake	Hoopnets	Winter	-	-	-	-	541	-	1,056	-	-	-	-	-	1,597
	Burbot	Kootenay River	Hoopnets	Winter	-	-	-	-	-	-	-	-	-	-	-	172	172
	Burbot	Kootenay Lake	Set Lines	Winter	-	-	-	-	1,167	-	-	-	-	-	-	-	1,167
	Burbot	Kootenay Lake	Gill Nets	Winter	-	-	-	-	2	-	-	-	-	-	-	-	2
	Burbot	Kootenay Lake	Rod-Reel	Winter	-	-	-	-	na	-	-	-	-	-	-	-	0
	Burbot	Goat River	Fence	Winter	-	-	-	-	-	-	-	-	-	26	-	-	26
	Burbot	Kootenay Lake	Cod Traps	Winter	-	-	-	-	-	-	137	-	256	-	-	-	393
	Burbot	Kootenay Lake	Remote Operated Vehicle	Winter	-	-	-	-	-	-	-	-	108	-	-	-	108
	Burbot	Kootenay Lake	Towable Operated Vehicle	Winter	-	-	-	-	-	-	-	-	-	7	-	-	7
	Burbot	Kootenay Lake	Dive Surveys	Winter	-	-	-	-	-	-	5	-	-	-	-	-	5
	Burbot	Kootenay Lake	Night Surveys	Winter	-	-	-	-	-	-	na	-	0.52	0.17			0.69
	Sturgeon	Kootenay Lake	Set Lines		?	?	?	?	?	?	?	?	?	?	?	?	?
MDFG	Burbot	Kootenai River	Hoopnets	Winter	-	-	-	-	-	32	-	-	-	-	-	-	32

Note: Where possible, effort units have been converted to days fished. With the ROV and TOV assessments, effort was measured in number of transects completed.
A dash indicates the gear was not used to sample burbot during that particular year. 'NA' indicates that the gear type was used to captured burbot, but effort data were not available for that gear type and year.

Larval Sampling

Larval burbot in the Kootenai River were sampled during spring using paired ½ m nets. Larval nets were towed in a downstream direction using an 8 m boat, with one net at the surface and the other approximately 1.5 m below the surface. The boat motor (150 hp) was operated at 1,000 rpm to maintain uniform towing speed. Current meters were mounted in the mouth of each net, and the volume of water filtered through each net was calculated using total towing time and rotation counts per second from the flow meters multiplied by net mouth area (0.785 m^2). Tows were made at mid channel near Ambush Rock (rkm 247) because of shallow water and debris near the river margin. Tows downstream to the mouth of the Kootenai River (rkm 124.7) were conducted near the shoreline. In addition, experiments to capture juvenile/age-0 burbot were conducted with minnow traps in 1995 and light traps in 2004.

In addition to these IDFG juvenile sampling efforts, BCMWLAP also conducted night surveys for juvenile burbot in Kootenay Lake, Goat River, and Summit Creek. Annual juvenile sampling effort is summarized in Table 7.

Analyses

The capture-recapture data consisted of various categories of fish, defined here as follows: (1) “captures” refers to all fish caught and sampled; (2) “tagged fish” are captures that were successfully tagged and released; (3) “within-season recaptures” are recapture events that occurred within a single sampling season; and (4) “between-season recaptures” are recaptures that occurred after one or more seasons. As discussed below, analyses of growth and abundance were based largely on data for between-season recaptures.

For some analyses, we organized the capture-recapture data into six different spatial “strata” defined by river km (described below). These strata were arbitrarily selected to represent distinct sections of the study area and to provide reasonable sample sizes for comparisons among strata.

Adult Size and Growth

Spatial and temporal patterns in size of captured adults were analyzed using length data. First, mean lengths of captures among strata were compared using analysis of variance (ANOVA). Data for four key strata were then pooled across consecutive three-year periods to examine potential changes in length distributions over time. This level of data aggregation provided reasonable sample sizes for comparing distributions. Mean lengths by period were compared using ANOVA, and linear regression was used to assess the time trend in annual estimates of mean length.

We used the capture-recapture data to estimate a tentative length-age relationship based on the length at infinity von Bertalanffy “LVB” growth model (Quinn and Deriso 1999):

$$L_i = L_\infty \left[1 - e^{-K(t_i - t_0)} \right] + w_i ,$$

where L is the length of fish i at age t, L_∞ is the asymptotic length, K is a growth parameter defining curvature, and t_0 is interpreted as the age when an individual would have been length 0 had the growth model been operative at all ages. Errors w were assumed to be additive and normally distributed with mean zero and standard deviation σ_w.

For recapture data, the LVB model can be formulated as:

$$L_{2i} = L_\infty(1-e^{-K\Delta t_i}) + L_{1i}e^{-K\Delta t_i} + w_i ,$$

where L_1 and L_2 denote the lengths of fish i at capture periods 1 and 2, respectively, and Δt_i is the elapsed time between periods. In this formulation, only L_∞ and K can be estimated. To fully specify the length-age relationship, the value for t_0 must be assumed or derived from auxiliary data (Quinn and Deriso 1999). We chose two values for t_0 (0 and -1) based on inspection of length-age curves derived for six North American burbot populations (Katzman and Zale 2000). By projecting these curves backward, it appeared that most curves would have intersected the X-axis (zero length) between hypothetical ages 0 and 1. Parameters L_∞ and K were estimated via maximum likelihood (nonlinear least squares), and approximate standard errors and confidence intervals were derived using likelihood theory (Kendall and Stuart 1979; Schnute 1992).

Abundance Estimates

Abundance and survival were estimated using variations of the Jolly-Seber model applied to between-season recapture data. Although there were more within-season recaptures than between-season recaptures, the former were deemed less useful for estimating abundance for two main reasons. First, 25 of the 45 within-season recaptures occurred in the 2001 sampling season at a single site (Ambush Rock and vicinity). The remaining within-season recaptures were sparsely distributed across sites and seasons, providing little data for use in closed-population models with repeated sampling such as the Schnabel method (Seber 1982). Second, because of the social nature of burbot during the spawning season, fish appeared to be attracted to a hoop net if another burbot was already present in the net, particularly in the case of males being attracted to a net that contained a female. This tendency, which was most obvious for 2001 Ambush Rock recaptures, can introduce bias and complicates estimation of capture probabilities (which likely differ among individuals because of apparent behavioral differences). In contrast, use of between-season recaptures provided a tentative framework for integrating different sampling sites and seasons, as well as for estimating annual (between-season) survival rates.

Table 7. Summary of juvenile burbot sampling effort by location, gear, and year.

Agency	Target Species	Location	Gear	Season	Year												Total
					1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	
IDFG	Burbot	Kootenai River	Mid-water Trawl	Winter	-	-	-	-	-	-	-	11,795 m^3	91,803 m^3	-	-	-	103,598 m^3
	Burbot	Kootenai River	D-ring Net	Spring/ Summer	-	-	-	na	-	-	-	-	-	-	-	-	-
	Burbot	Kootenai River	Drift Net	Spring/ Summer	-	-	-	na	-	-	-	-	-	-	-	-	-
	Burbot	Kootenai River	Towed Meter Nets	Spring/ Summer	-	-	-	na	-	-	-	-	-	-	-	-	-
	Burbot	Kootenai River	Shrimp Trawl	Spring/ Summer	-	-	51,763 m^3	na	-	-	-	-	-	-	-	-	51,763 m^3
	Burbot	Kootenai River	Gill Nets	Spring/ Summer	-	-	12	-	-	-	-	-	-	-	-	-	12
	Burbot	Kootenai River	Hoopnets	Spring/ Summer	-	-	244	-	-	-	-	-	-	-	-	-	244
	Burbot	Kootenai River	Minnow Traps	Spring/ Summer	-	-	94	-	-	-	-	-	-	-	-	-	94
	Burbot	Kootenai River	Slat Traps	Spring/ Summer	-	-	43	-	-	-	-	-	-	-	-	-	43
	Burbot	Kootenai River	Beach Seine	Spring/ Summer	-	-	15	-	-	-	-	-	-	-	-	-	15
	Burbot	Kootenai River	Electrofishing	Spring/ Summer	-	-	0.25	-	-	-	-	-	-	-	-	-	0
	Sturgeon	Kootenai River	Hoopnets, Set Lines	Summer	?	?	?	?	?	?	?	?	?	?	?	?	?
BCMELP	Burbot	Kootenay Lake	Night Surveys	Winter	-	-	-	-	-	-	na	-	0.52	0.17	?	?	0.69
	Burbot	Kootenay Lake	Mid-water Trawl	Winter	-	-	-	-	12.2×10^6 m^3	-	-	-	-	-	-	-	12.2×10^6 m^3
	Burbot	Kootenay Lake	Electrofishing	Winter	-	-	-	-	-	-	7,044 m^2	-	-	-	-	-	7,044 m^2
	Burbot	Kootenay Lake	Minnow Traps	Winter	-	-	-	-	-	-	61	-	-	-	-	-	61
	Burbot	Kootenay Lake	Beach Seine	Winter	-	-	-	-	-	-	na	-	-	-	-	-	-
	Sturgeon	Kootenay Lake	Set Lines		?	?	?	?	?	?	?	?	?	?	?	?	?

Note: Where possible, effort units have been converted to days fished. For mid-water and shrimp trawl gear, effort was measured in volume of water sampled. IDFG beach seine effort measured by the number of hauls. For electrofishing, IDFG effort was measured in days fished and BC effort in area sampled. A dash indicates the gear was not used to sample burbot during that particular year. 'NA' indicates that the gear type was used to captured burbot, but effort data were not available for that gear type and year.

The standard Jolly-Seber model was designed for "open" populations subject to mortality (or permanent emigration) and recruitment (or immigration) (Seber 1982, p. 196). When capture and recapture events occur across multiple time periods, as in the burbot data set, the model permits estimation of period-specific capture probabilities (p_t) and survival rates ($ø_t$). In turn, these parameters are used to estimate abundance (N_t) and net recruitment (B_t) by period. The accuracy and reliability of estimates will depend on the number of recaptures and the degree to which assumptions of the model are met. In general, Seber (1982) suggests that at least ten recaptures per release period and per recovery period are required to provide reasonable estimates of p_t and $ø_t$. For Kootenai burbot, however, the total number of between-season recaptures for a given release year or recovery year ranged from zero to a maximum of eight.

Given so few recaptures, the number of parameters in the model had to be reduced (e.g., Brownie et al. 1986). Eight alternative models were explored. In the first model (denoted the "no-effort" model), data were pooled across four key strata to maximize recaptures, and capture probabilities and survival rates were assumed to be constant across years, such that $p_t = p$ and $\sigma_t = ø$ for all t. This model had two parameters (p, $ø$) to be estimated. (Estimates of abundance and recruitment were still available by year.) While a constant survival rate seems plausible, a constant p may be a poor assumption, especially given that effort differed appreciably among years. Thus, in the second model we assumed that annual capture probabilities were a function of total hoop net effort (E_t) (Seber 1982, p. 296):

$$p_t = 1 - e^{-qE_t}$$

The catchability coefficient, q, was assumed to be constant over time. To more readily interpret parameter estimates, we scaled annual effort by the mean effort across years ($\tilde{E}_t = E_t / \overline{E}$) and defined q as:

$$q = -\log(1 - \tilde{p})$$

where $\tilde{p}$ is the "average" capture probability or probability of capture at $E_t = \overline{E}$. Thus, the "effort" model also had two parameters ($\tilde{p}$, $ø$). For simplicity, we use notation p rather than $\tilde{p}$ when referring to the capture probability for an effort model.

In the remaining six models, data were divided into two groups. A potential problem with the above models is that capture probabilities were assumed to be identical across strata, yet sampling effort often differed markedly among strata. As discussed below, one stratum in particular had a distinct sampling history and few between-stratum recaptures, thereby indicating reasonable independence. We therefore treated this stratum and the remaining strata as two separate groups. Parameters were estimated either jointly or separately across the two groups as follows: In the first model, both groups were assumed to have the same capture probability (p) and survival rate ($ø$) (two parameters). Second, groups were assumed to have the same $ø$ but different capture probabilities (p_1, p_2) across years (three parameters in total). Last, groups were assumed to have different survival rates ($ø_1$, $ø_2$) as well as different capture probabilities (four parameters). We then repeated these analyses using models that incorporated hoop net-effort data as described above.

Models were fit via maximum likelihood and compared using Akaike's information criterion (AIC) (Hurvich and Tsai 1989; Burnham and Anderson 1998). This criterion measures the relative support of alternative models based on their likelihoods and numbers of parameters. The model with the lowest AIC is considered the "best" model. In general, alternative models are considered to have strong, moderate, weak, or very little support if their AIC values differ from the lowest by less than 2, 2 to 4, 4 to 7, or more than 7, respectively (Burnham and Anderson 1998). Unlike the standard Jolly-Seber model, there are no analytical formulas for computing standard errors for reduced-parameter models (Brownie et al. 1986). We therefore used likelihood theory to estimate approximate standard errors and confidence intervals for one selected model (Kendall and Stuart 1979; Schnute 1992). For all models, estimates of annual abundance (N_t) and net recruitment (B_t) were summarized in terms for their averages across years and their linear trends over time. The latter was computed as the annual percent change relative to the average (e.g., slope[N_t vs. t]/ $\overline{N}$ * 100). Finally, we examined several assumptions underlying the abundance models as discussed below.

Population Model

We used a simple deterministic model to explore relationships between expected length-frequency distributions of adult burbot and biological parameters related to growth, survival, recruitment, and capture vulnerability. This analysis was motivated by the fact that burbot length data are likely the most reliable and potentially informative data for inferring reasonable bounds for basic biological parameters. In sum, the model projected age-specific abundances and lengths of consecutive cohorts over time and evaluated the congruency between observed and expected length distributions under different parameter assumptions.

The age-specific abundance (N_a) in year t was modeled as $N_{a,t} = \phi N_{a-1,t-1}$, where the survival rate ø was assumed to be constant across ages and years. Ages 3 through 12 were modeled with each cohort initiated at an arbitrary abundance (recruitment) of age-3 fish (N_3). Age-specific length distributions were modeled using the LVB model described above, but with the important distinction that ages were assumed known. Finally, age-specific selectivity (capture vulnerability) was modeled using a logistic function with selectivity increasing with age to an asymptote of one (Quinn and Deriso 1999):

$$s_a = 1 - \frac{1}{1 + e^{n_1(a - n_2)}}$$

Here, n_1 defines the slope of the selectivity curve and n_2 is the inflection point or age of 50% selectivity.

Using this framework, we explored several scenarios in which survival and growth parameters were fixed and then selectivity parameters were crudely estimated to provide a reasonable agreement between observed and expected length distributions. Parameter values were obtained by minimizing the sum of squared differences between observed and expected length frequencies (ranging from 300 to 800 mm in increments of 10 mm). Further details of specific scenarios are provided below.

RESULTS

Summary of Adult Sampling

Since 1993, considerable fishing effort has focused on Kootenai River burbot; additionally, several burbot have been captured during sampling targeting sturgeon (Table 6). Total captures and recaptures are summarized in Table 8. These data include burbot captured during IDFG winter burbot sampling, BCMWLAP winter sampling, and incidental catch during IDFG summer sturgeon sampling. Across years, there were 403 capture events from which 300 burbot were newly tagged and released. Of the remaining 103 capture events, 45 were within-season recaptures, 27 were between-season recaptures, and 31 were cases in which burbot were not tagged. None of the burbot tagged in the 1993-1995, 1997, and 2003 sampling seasons was recaptured in subsequent years (Table 8).

Hoop net effort varied annually since 1993, but generally increased over time (Table 9 and Figure 14). Catch also increased until 2001 but then declined substantially. Catch per unit of effort (CPUE) was highly variable from 1993 through 1998 and declined steadily thereafter (Table 9 and Figure 14). Hoop net effort and burbot captures were concentrated in three discrete areas within the Kootenai River: Goat River (rkm 152.7), Boundary Creek (rkm 170), and Ambush Rock (rkm 244.5; Figure 15).

Data were divided into six spatial strata to facilitate analyses (Table 10). Stratum 1 represented data collected in Kootenay Lake; strata 2, 4, and 6 represented long sections of the Kootenai River (strata 6 was sampled in the 1993 winter season but little thereafter); and stratum 3 (Goat River) and stratum 5 (Ambush Rock and vicinity) represented key spawning locations. Although the majority of captures occurred in strata 3 and 5, more effort was devoted across years to strata 2 and 4 (Table 10).

Table 8. Summary of annual adult burbot captures and recaptures in the Kootenai River, 1993-2004.

	Number of Burbot																	
	Captured				Recaptured													
Year	Total Captured	New Tags	Between Season Recaps	Within Season Recaps	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total	Recap %
1993	17	15	0	1	-	0	0	0	0	0	0	0	0	0	0	0	0	0%
1994	15	9	0	1	-	-	0	0	0	0	0	0	0	0	0	0	0	0%
1995	33	20	0	0	-	-	-	0	0	0	0	0	0	0	0	0	0	0%
1996	34	30	0	1	-	-	-	-	3	3	2	0	0	0	0	0	8	27%
1997	24	21	3	0	-	-	-	-	-	0	0	0	0	0	0	0	0	0%
1998	59	50	3	3	-	-	-	-	-	-	1	0	0	0	0	0	1	2%
1999	47	40	3	2	-	-	-	-	-	-	-	1	1	0	0	0	2	5%
2000	36	31	1	3	-	-	-	-	-	-	-	-	7	2	0	1	10	32%
2001	74	40	8	26	-	-	-	-	-	-	-	-	-	5	0	1	6	15%
2002	33	19	7	5	-	-	-	-	-	-	-	-	-	-	0	0	0	0%
2003	11	10	0	0	-	-	-	-	-	-	-	-	-	-	-	0	0	0%
2004	20	15	2	3	-	-	-	-	-	-	-	-	-	-	-	-	0	0%
Totals	403	300	27	45	0	0	0	0	3	3	3	1	8	7	0	2	27	9%

Note: The year convention used in this table corresponds to the sampling year and NOT the calendar year. The sampling year began in the winter (roughly on November 1) and continued through the following spring (except for limited summer sampling in 1994 and 1996).

Table 9. Kootenai River burbot catch, effort, and CPUE by sample season, 1993-2004 (IDFG winter hoop net effort only).

Sample season	Burbot Captures[a]	Total Hoopnet Days	CPUE (fish/net day)
Wtr 1993	16	554.2	0.029
Wtr 1994	8	909.8	0.009
Wtr 1995	33	688.8	0.048
Wtr 1996	27	495.8	0.054
Wtr 1997	23	1,061.1	0.022
Wtr 1998	40	1,240.9	0.032
Wtr 1999	44	1,453.7	0.030
Wtr 2000	34	1,712.9	0.020
Wtr 2001	47	2,085.2	0.023
Wtr 2002	16	1,529.9	0.010
Wtr 2003	11	1,809.7	0.006
Wtr 2004	16	1,965.1	0.008
Total	*315*	*15,507.1*	*0.020*

[a] Burbot captured in the same location during the same sampling season were not considered recaptures and were dropped from the analysis.

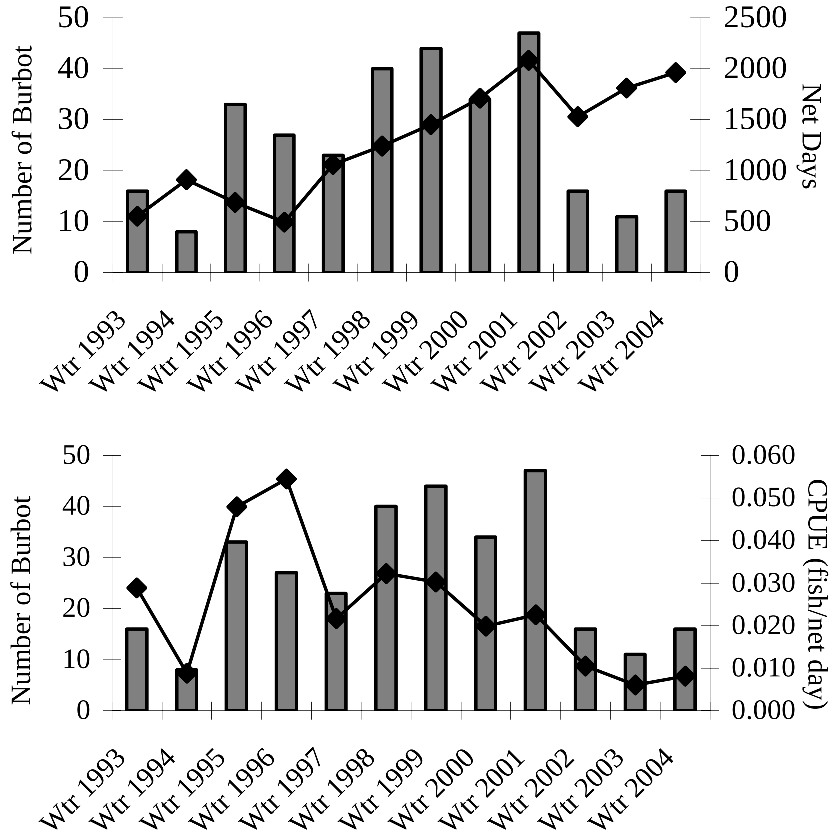

Figure 14. Kootenai River burbot sampling effort and CPUE trends over time, 1993-2004 (IDFG winter hoop net effort only). Note: Bars represent the number of burbot in each graph while the line represents the effort and CPUE in the top and bottom graphs, respectively.

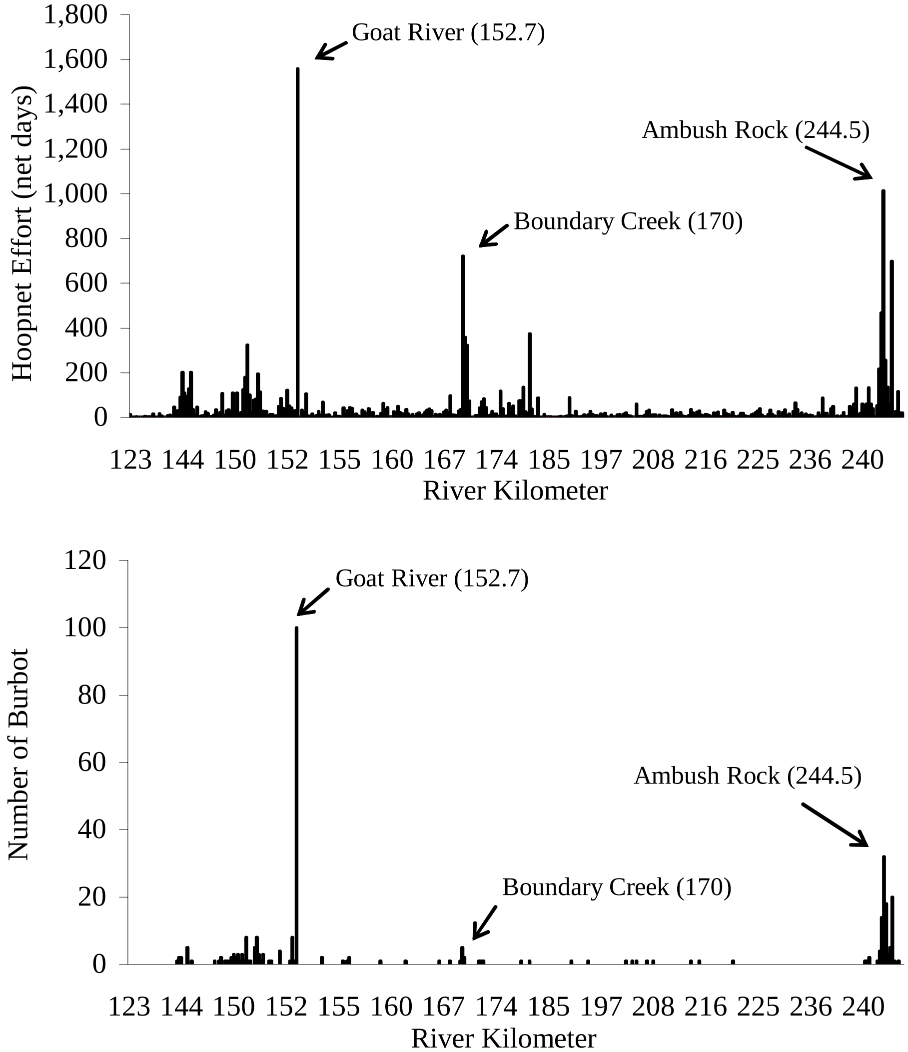

Figure 15. Hoop net effort and catch by river kilometer, 1993-2004 (includes only IDFG winter hoop net effort).

Table 10. Kootenai River burbot capture data (across all gear types) by strata, 1993-2004 (IDFG winter hoop net effort only).

						Recaptures	
Stratum	**RKM**	**Description**	**Hoop net Effort**	**Captures**	**Tagged**	**Within-season**	**Between-Season**
1	15.7-121.9	Kootenay Lake	na	24	16	1	0
2	123.5-152.6	Kootenai River	3628	76	65	1	5
3	152.7	Goat River	1560	127	103	8	7
4	153.6-242.0	Kootenai River	7238	46	39	3	2
5	244.2-245.0	Ambush Rock	2896	129	76	32	13
6	249.4-270.0	Kootenai River	186	1	1	0	0
Totals				403	300	45	27

Burbot movement was tracked using data on recaptured fish. (Note that IDFG has conducted annual burbot radio telemetry tracking to record fish movement; these data are summarized in the various IDFG annual progress reports to BPA and Paragamian 2000). Few burbot were recaptured at a location different from the initial capture location (Figure 16). Of those burbot recaptured at different locations, maximum distances traveled between capture locations approached 100 km. Duration between capture events at the same location was as long as three years (Figure 17).

Summary of Larval Sampling

One young-of-the-year juvenile burbot was captured in Kootenai River by minnow trap in 1995 and only one larval burbot in a ½ m net tow downstream of Goat River in March 1999. No larval burbot was captured in the recent two years (2000 and 2001) of sampling in Kootenai River. In Kootenay Lake, 37 juvenile burbot have been observed since 1997; all but one were observed during night spotlight surveys at the North Arm of Kootenay Lake. The other juvenile burbot was captured using electrofishing. Although over 300 non-target larval and juvenile fish were captured with 625 h of light trap effort in 2004, no larval burbot was caught.

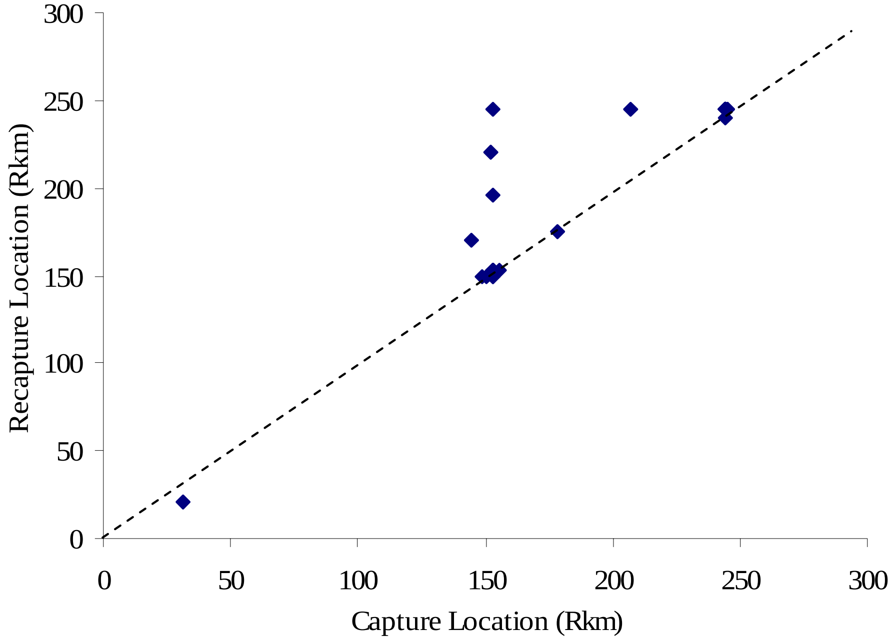

Figure 16. Comparison of initial capture location and location of recapture (dashed line represents no difference in capture and recapture location).

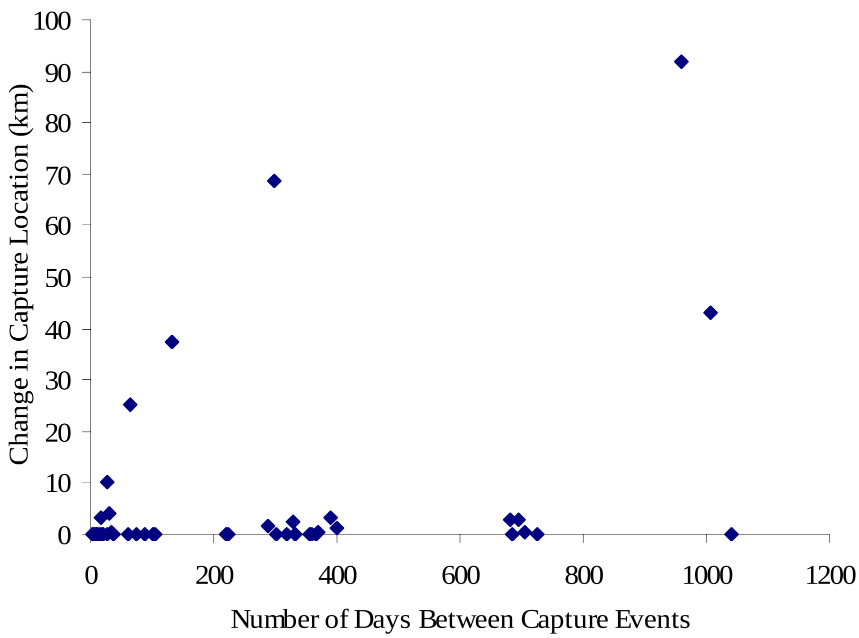

Figure 17. Comparison of duration between capture events and the change in capture locations.

Adult Size and Growth

The length-frequency distribution for all burbot captures was highly symmetric, with mean = 578 mm and standard deviation = 117 mm (Figure 18). Kootenai River burbot follow a typical exponential length-weight relationship (Figure 19). Males and females fit a similar exponential curve, although the steepness of the female curve was higher than that for males.

There were obvious spatial and temporal differences in lengths of captured fish. Across all years, length distributions were remarkably consistent for strata 2 through 5, but fish captured in stratum 1 (Kootenay Lake) tended to be much larger (Figure 20). Mean lengths for strata 2-5 were similar (range: 560 to 577 mm), while the mean length for stratum 1 (743 mm) was significantly larger (ANOVA, P <0.001) with only a single capture (Figure 21).

Consequently, to analyze temporal trends in length, we omitted fish from stratum 1 because of their anomalous size and because most fish were captured in only two years (1996 and 1998) and the single capture in 6. For the remaining data (pooled across strata 2 through 5), there was a clear trend toward larger lengths in later time periods. Length distributions for combined three-year periods showed subtle but important differences (Figure 22). For the first three-year period (1993-1995), there was an obvious “shoulder” in the distribution at lower lengths. In contrast, a similar shoulder existed at higher lengths in the final period (Figure 22). Differences in mean lengths for the four periods were highly significant (ANOVA, P <0.001) (Figure 23). In general, mean length increased by roughly 8 mm/yr on average from 516 mm in 1993 to 629 mm in 2004 (Figure 24).

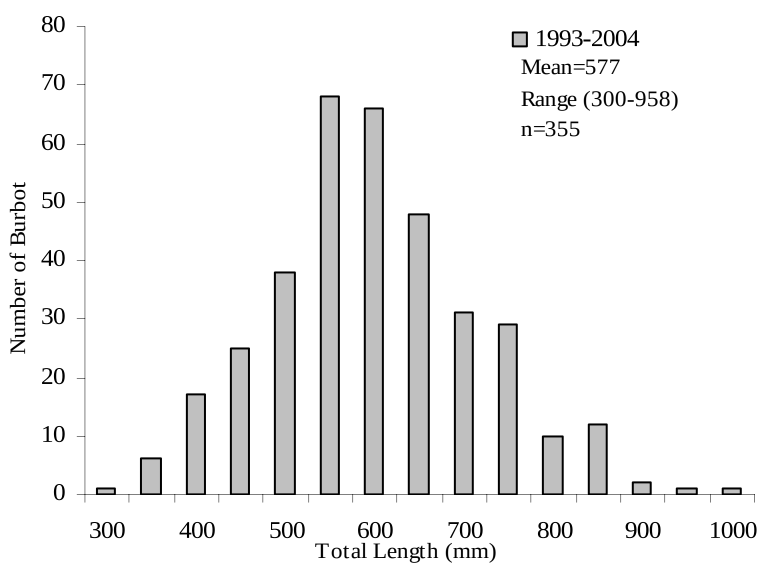

Figure 18. Length-frequency distribution for burbot captures and recaptures, 1993-2004 (same season/location recaps removed from analyses).

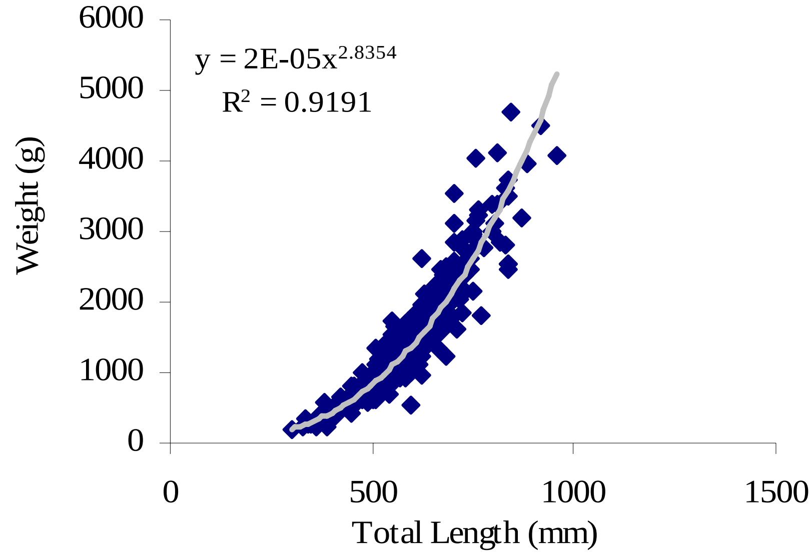

Figure 19. Length-weight relationship for burbot captures, 1993-2004.

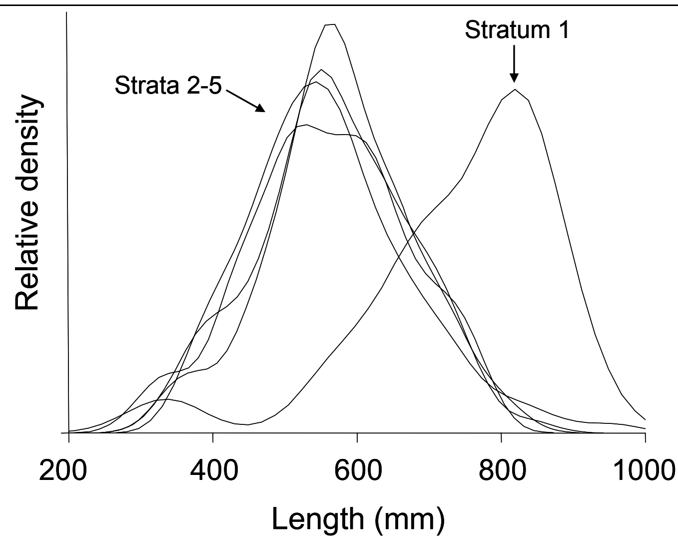

Figure 20. Length distributions (density functions) for burbot captures by strata, 1993-2004.

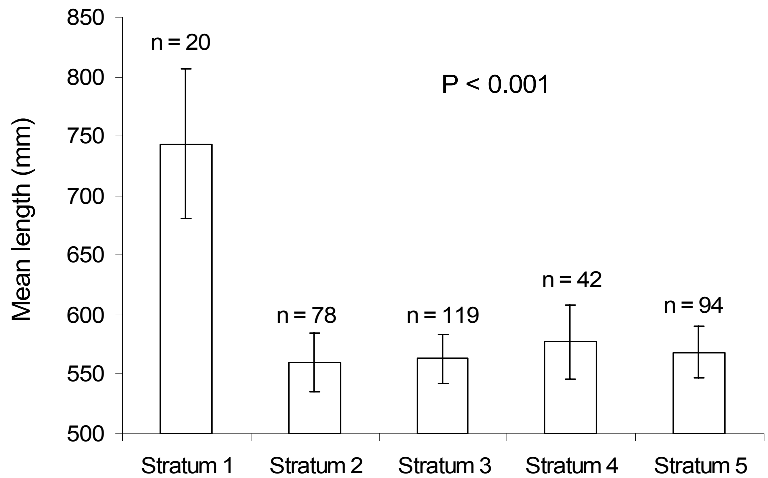

Figure 21. Mean lengths and 95% confidence intervals for burbot captures by strata, 1993-2004.

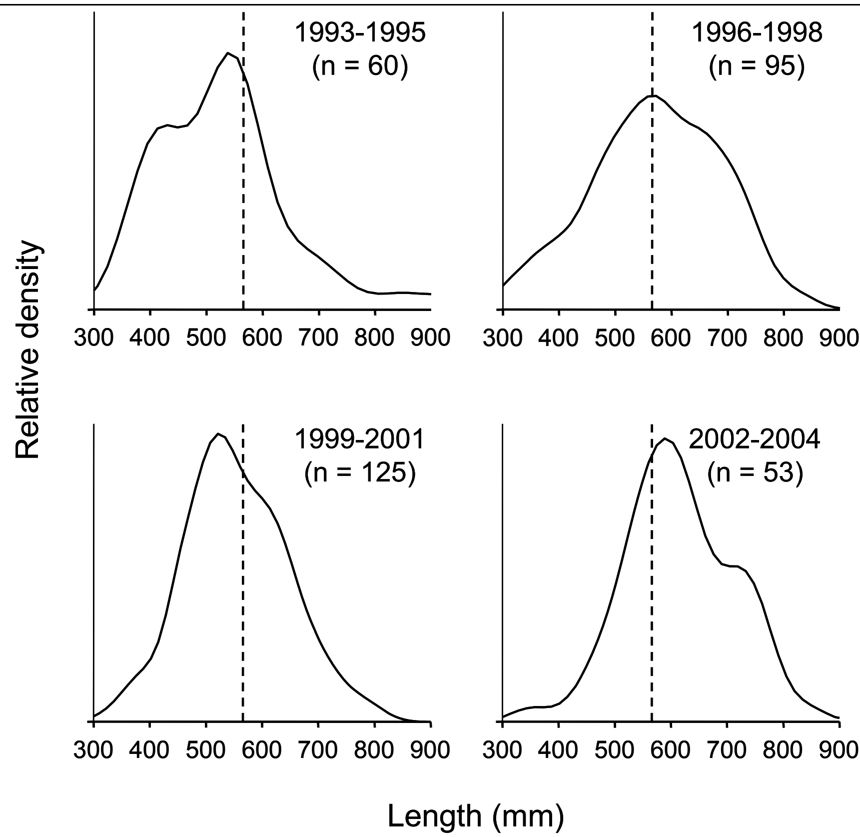

Figure 22. Length distributions by period for burbot captured in strata 2-5 (dashed line is the grand mean).

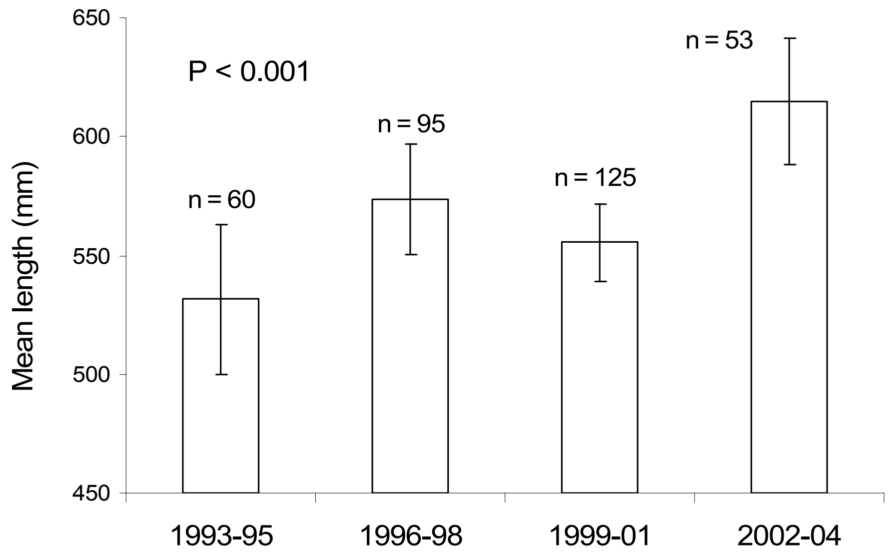

Figure 23. Mean lengths and 95% confidence intervals by period for burbot captured in strata 2-5.

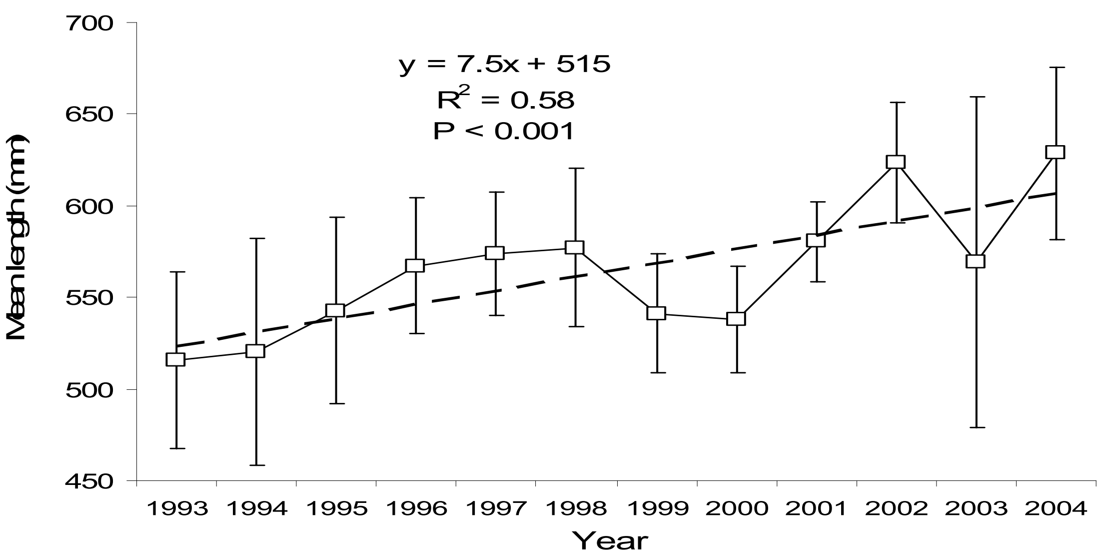

Figure 24. Annual mean lengths and regression against year for burbot captured in strata 2-5.

Growth of burbot (measured in both length and weight) was tracked using data for recaptured fish. Changes in length and weight were a function of time (Figure 25). In some instances, there was a negative change in length or weight over time; negative growth was measured more often using weight as a metric rather than length.

We estimated tentative length-age relationships using data for 28 recaptures. Elapsed time between initial capture and recapture events ranged from 63 to 1040 days (median = 358), while observed annual growth increments ranged from 0.0 to 88 mm/yr (median = 40). Observed growth increments declined slightly as a function of initial length (Figure 26).

Parameter estimates for the LVB growth curve were highly uncertain (Table 11; Figure 27), yet provided sensible length-age relationships given assumed values of t_0 (Figure 28). Both curves in Figure 28 are generally consistent with length-age relationships of other North American burbot populations, though at the low end (Katzman and Zale 2000). Across the six populations presented in Katzman and Zale (2000), mean lengths of age-1 fish range from roughly 100 to 200 mm, while lengths of age-10 fish range from roughly 600 to 800 mm, depending on the population. (Note that the “example” parameter combination in Figure 27 and growth curve in Figure 28 are discussed below in relation to the “Population Model.”)

The curves in Figure 28 should be interpreted cautiously because they are based on assumed values of t_0 and imprecise LVB estimates. In addition, growth curves based on recapture data have a somewhat different interpretation than standard size-age curves (where age is known) and may, therefore, result in different estimates (Quinn and Deriso 1999). Specifically, the recapture model estimates growth as a function of size rather than age. Also, the estimate of σ_w (28.3 mm) is properly interpreted as the standard deviation in annual growth rates across individuals, which incidentally is quite large (Figure 26), rather than as the standard deviation of lengths at a given age.

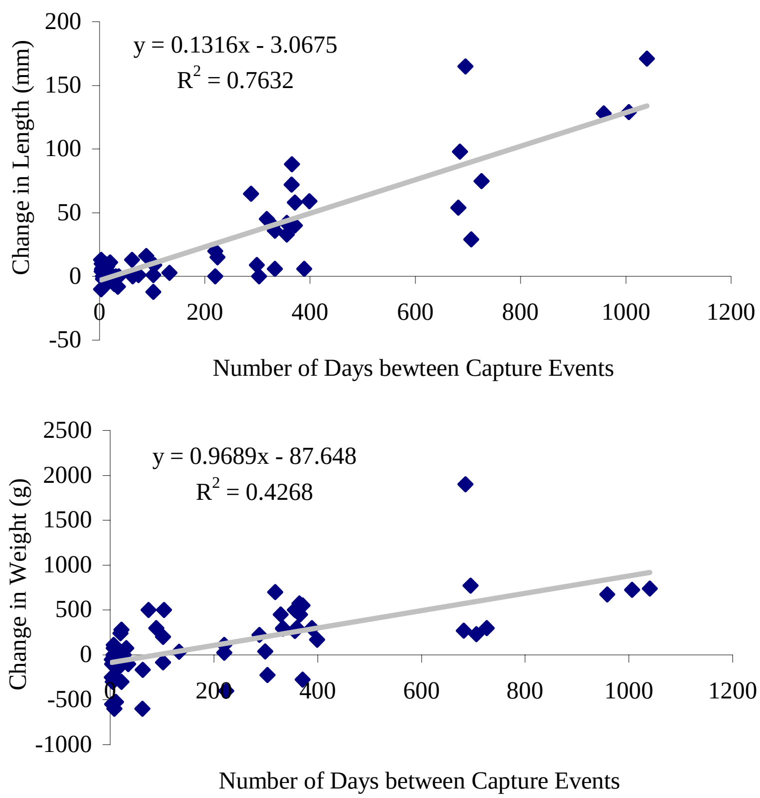

Figure 25. Growth of recaptured burbot between capture events.

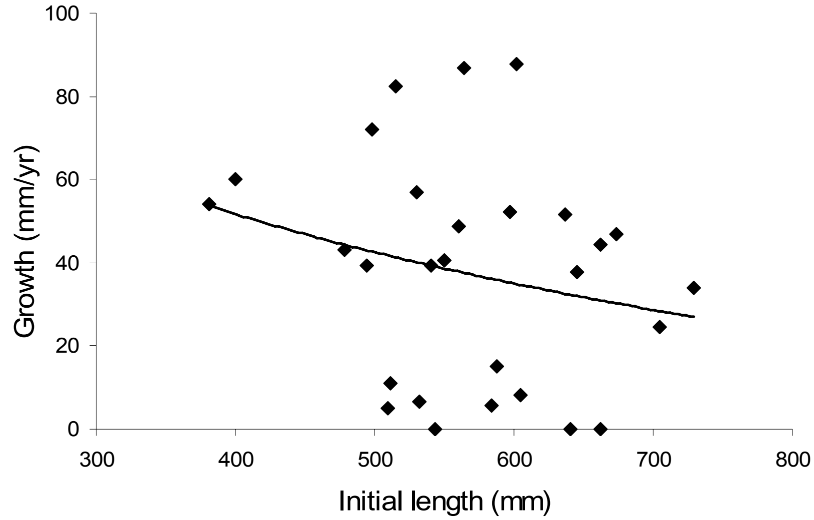

Figure 26.   Annual growth increments in length (mm/yr) for 28 recaptures.

Table 11. Parameter estimates and standard errors for the LVB growth model fit to length data for 28 capture-recapture events for Kootenai burbot.

Parameter	Estimate	SE
K	0.052	0.047
L_{∞} (mm)	1517	834
σ_w (mm)	28.3	

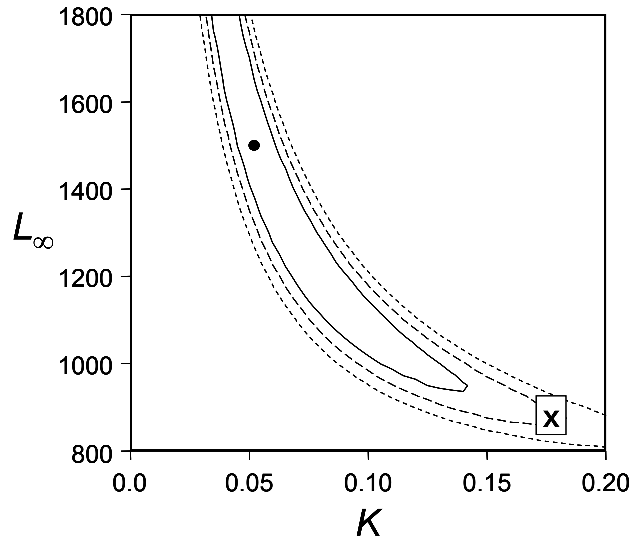

Figure 27. Joint confidence regions (solid line: 80%; dashed line: 95%; dotted line: 99%) for parameters of the LVB growth model. "X" corresponds to parameters values for a hypothetical example.

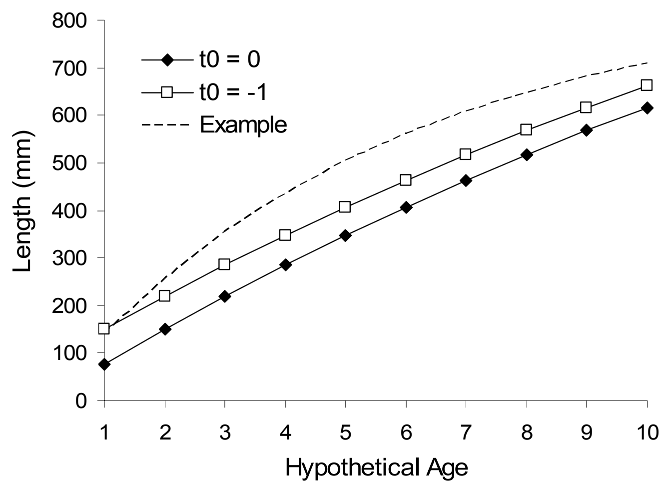

Figure 28. Length-age curves based on the LVB model fit to recapture data for Kootenai burbot. Curves are shown for two assumed values of t_0 (0 and -1) and a hypothetical example.

Abundance Estimates

Combined-Strata Models

Abundance and survival were first estimated using data pooled across strata 2-5 for sampling seasons 1996-2004. As noted earlier, none of the burbot tagged in the 1993-1995 seasons was recaptured during subsequent seasons, and hence these years were omitted from all analyses.

The “effort” model for the combined strata provided a slightly better fit (lower AIC) than the “no-effort” model, but both models provided similar parameter estimates (Table 12). Estimates of capture probability ($p \approx 0.2$) imply that roughly 20% of the population was sampled on average, while estimates of survival ($ø \approx 0.4$) imply fairly low annual survival rates of roughly 40% on average. Averages of annual abundance (N_t) and net recruitment (B_t) estimates were roughly 150 and 90, respectively (Table 12). Abundance estimates for both models declined over time (Figure 29), though the average decline was greater for the effort model (14%/yr) than for the no-effort model (8%/yr; due primarily to the low abundance estimate in 2003). Larger declines were evident for recruitment estimates (Figure 30). In this case, the decline was greatest for the no-effort model (Table 12).

Table 12. Parameter and abundance estimates for capture-recapture models (strata 2-5). Approximate 95% confidence intervals for parameters of the “effort” model are shown in parentheses.

Model		**Capture probability**	**Survival**	**Average**		**Decline (%/yr)**	
	AIC	***P***	**ø**	N_t	B_t	N_t	B_t
No effort	212.2	0.21	0.40	153	95	8%	27%
Effort	211.5	0.24 (0.12–0.41)	0.37 (0.24–0.50)	148	77	14%	21%

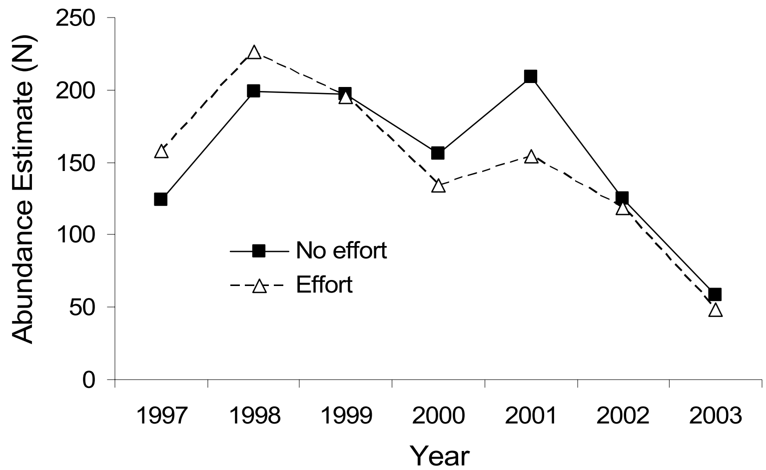

Figure 29. Estimates of Kootenai burbot abundance (N_t) for capture-recapture models (strata 2-5).

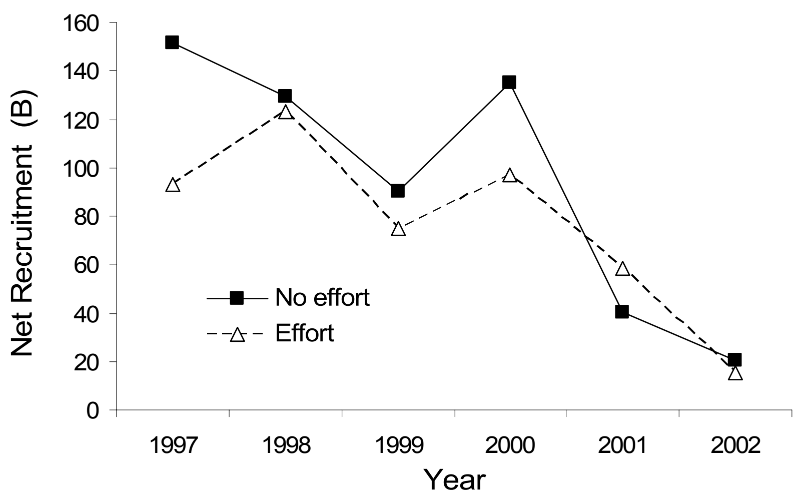

Figure 30. Estimates of Kootenai burbot recruitment (B_t) for capture-recapture models (strata 2-5).

The precision of parameter estimates and implications for abundance estimates were explored for the effort model. The marginal 95% confidence intervals for each parameter and their joint confidence regions indicate considerable uncertainty (Table 12, Figure 31). Abundance estimates, however, were far more sensitive to changes in $\hat{p}$ than $\hat{\phi}$. Figure 32 shows the average abundance estimate ($\hat{\bar{N}}$), integrated across $\hat{\phi}$, as a function of $\hat{p}$. The approximate 95% confidence interval for $\hat{p}$ corresponded to a range of $\hat{\bar{N}}$ from 85 at $\hat{p}$ = 0.41 to 294 at $\hat{p}$ = 0.12 (Figure 32). Changes to either $\hat{p}$ or $\hat{\phi}$ essentially scaled all annual abundance estimates either upward or downward, and hence, estimated declines in abundance (≈ 14%/yr) changed little across combinations of $\hat{p}$ and $\hat{\phi}$.

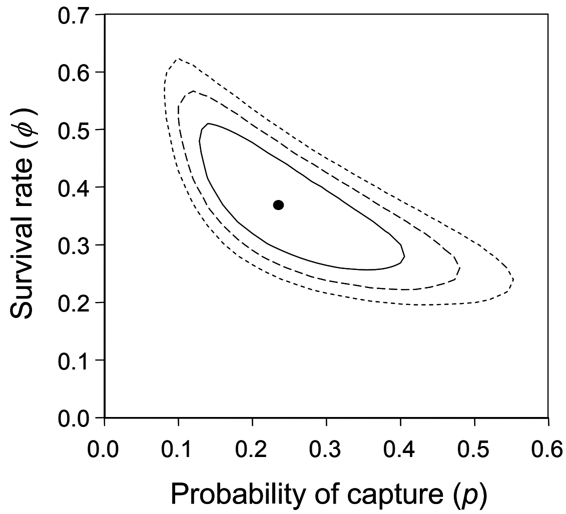

Figure 31. Joint confidence regions (solid line: 80%; dashed line: 95%; dotted line: 99%) for parameters of the “effort” capture-recapture model (strata 2-5, 1996-2004).

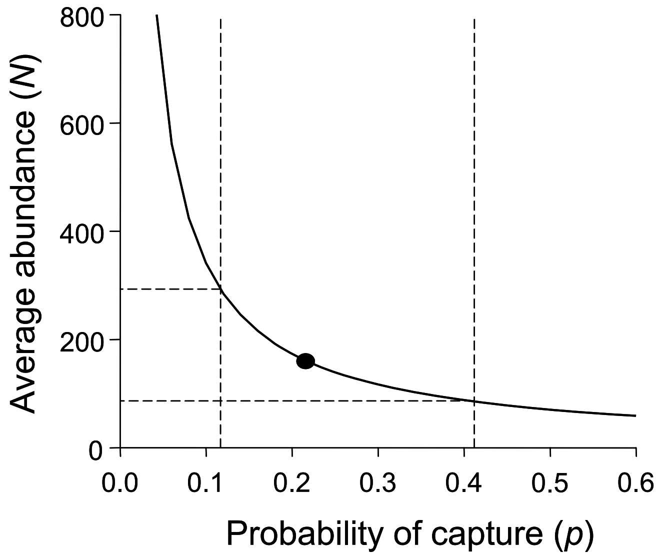

Figure 32. Estimates of average Kootenai burbot abundance (strata 2-5, 1997-2003) as a function of capture probability (p) for the “effort” model. Dashed lines indicate the 95% confidence interval for p and the corresponding average abundances (integrated across ø).

Two-Stratum Models

The above models assumed that all (living) fish had equal probabilities of capture across strata. However, neither fish nor sampling effort could be considered uniformly distributed. The most obvious discrepancies were for stratum 5 (Ambush Rock and vicinity). For example, all 11 burbot released from this stratum were also recaptured there, while only two fish released from other strata were recaptured in stratum 5 (Table 13). Greater mixing was apparent among strata 2-4 (Table 13). In addition, there was a large increase in hoop net effort for stratum 5 after the 2000 sampling season, while effort varied less for strata 2-4 (Figure 33).

Table 13. Total burbot recaptures partitioned by stratum of release and recapture (1996-2004).

Release Stratum	Recapture Stratum S 2	S 3	S 4	S 5
S 2	1		1	
S 3	4	6	1	1
S 4		1		1
S 5				11

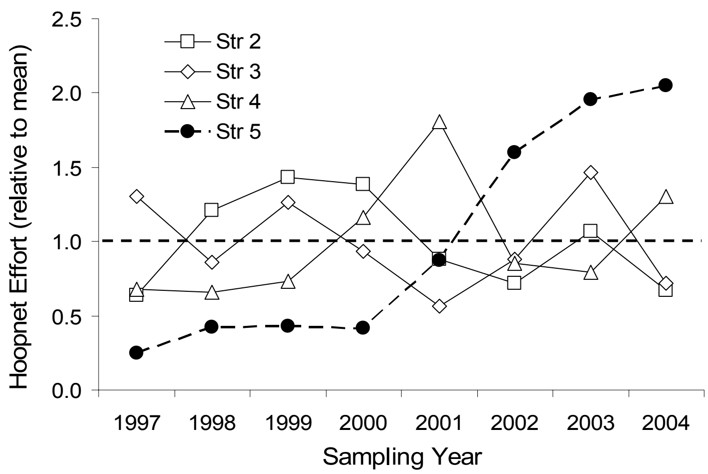

Figure 33. Variability in hoop net effort by stratum (Str) and year. Annual effort was divided by the mean across years for a given stratum (dashed line at 1.0 indicates the mean).

We therefore treated strata 2-4 and stratum 5 as separate groups in the “two-stratum” models, which required omission of the two stratum 5 recaptures not released in that stratum (Table 13). For effort-based models, the effort index for strata 2-4 was computed as a weighted average of their scaled indices (Figure 33), with arbitrary weights (1, 4, and 2, respectively) roughly reflecting the relative number of recaptures in each stratum (Table 13). However, variability in the effort index was minimal regardless of the weighting scheme, and hence results were robust to alternative weightings.

Results for the two-stratum models suggested that capture probabilities differed considerably between the two groups (Table 14). The no-effort models outperformed effort models based on AIC; however, in either case, the best model incorporated different capture probabilities (p_1, p_2) and a common survival rate ($ø$) (Table 14, Models B and E). The estimate of p for stratum 5 was generally twice that for strata 2-4. The main consequence of differing capture probabilities was an overall increase in abundance estimates (Table 14). On average, total abundances (N) were slightly greater than 200 for Models B and E. By comparison, average abundances for the combined-strata models were roughly 150 (Table 12). Models that allowed for different survival rates ($ø_1$, $ø_2$) also performed well based on AIC (Table 14, Models C and F). These models suggested that both p and $ø$ were larger for stratum 5 than for strata 2-4.

Declines in total abundance for two-stratum models (Table 14) were similar to those for combined-strata models (Table 12). For example, abundance and recruitment estimates are shown in Figure 34 and Figure 35 for Model E. Abundances in strata 2-4 appeared to decline steadily after 1998, while abundances in stratum 5 increased until 2001 (Figure 34). The net result was a somewhat stable trajectory for total abundance until 2001, followed by a sharp decline. Declining trends in total recruitment for two-stratum models (Table 14) were largely driven by sharp declines after 2000 (Figure 35).

Table 14. Parameter and abundance estimates for the "two-stratum" capture-recapture models. Parameters with subscripts "1" and "2" correspond to estimates for strata 2-4 and stratum 5, respectively.

						Average *N*			**Average *B***			**Trend in *N* (%/yr)**			**Trend in *B* (%/yr)**		
Model	**Effort**	**Parameters**	**AIC**	***p***	***ø***	**S 2-4**	**S 5**	**Total**	**S 2-4**	**S 5**	**Total**	**S 2-4**	**S 5**	**Total**	**S 2-4**	**S 5**	**Total**
A	No	p, ø	198.1	0.22	0.37	105	41	147	51	46	97	-20	+24	-7	-27	-24	-26
B	Effort	p_1, p_2, ø	192.8	0.13, 0.41	0.42	179	22	202	73	26	99	-20	+24	-15	-31	-23	-28
C		p_1, p_2, $ø_1$, $ø_2$	193.7	0.18, 0.33	0.34, 0.51	134	28	161	66	30	96	-20	+24	-12	-27	-27	-27
D	Effort	p, ø	199.3	0.20	0.37	118	60	177	52	60	112	-20	+8	-10	-25	-37	-31
E		p_1, p_2, ø	197.0	0.14, 0.34	0.40	174	35	209	69	35	104	-20	+9	-15	-27	-34	-29
F		p_1, p_2, $ø_1$, $ø_2$	198.3	0.18, 0.29	0.33, 0.46	135	41	176	63	39	102	-20	+9	-13	-24	-38	-30

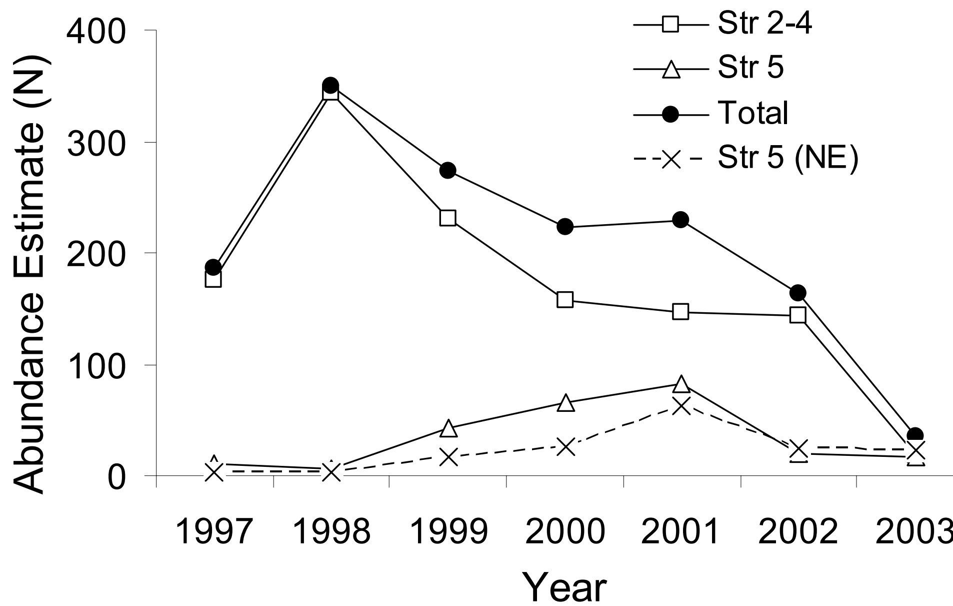

Figure 34. Estimates of Kootenai burbot abundance (N_t) for Model E (effort). Also shown are abundance estimates for stratum 5 for Model B (no effort, NE).

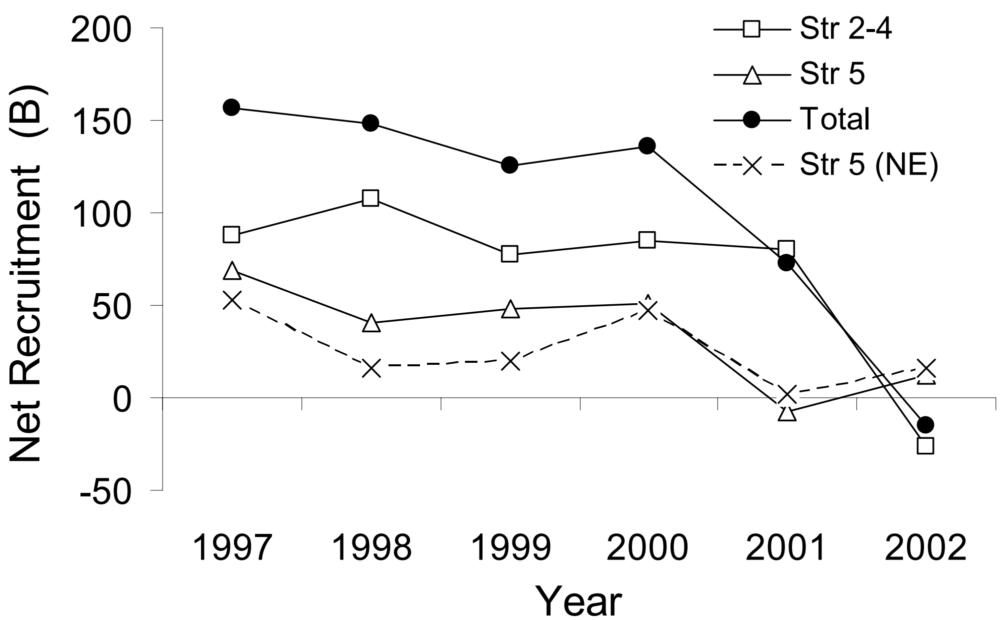

Figure 35. Estimates of Kootenai burbot recruitment (B_t) for Model E (effort). Also shown are recruitment estimates for stratum 5 for Model B (no effort, NE).

Finally, including effort influenced results primarily through stratum 5. In effort models, estimates of p_t for stratum 5 increased over time from roughly 0.1 to 0.5 in accordance with the strong trend in effort (Figure 33). Consequently, abundance and recruitment estimates for stratum 5 were sensitive to the use of effort (Table 14), though differences were subtle in comparison to the overall abundance or recruitment trends (Figure 34 and Figure 35).

Validity of Assumptions

Several assumptions underlie the abundance and recruitment estimates of the above models (e.g., Seber 1982, p. 196): 1) every fish, whether tagged or untagged, has the same probability of capture either across all sampling seasons (no-effort models) or within a given sampling season (effort models); 2) every tagged fish has the same probability of surviving from one period to the next and of being present in the population during subsequent sampling periods; 3) tagged fish do not lose their tags and all tags are reported on recovery; 4) samples are instantaneous (sampling time is negligible); and 5) the survival rates of tagged and untagged fish must be the same for recruitment estimates to be valid.

Depending on the model, it was assumed that capture probabilities were equal across strata, across time periods, and/or proportional to sampling effort. Thus, assumption 1 was undoubtedly violated given that attributes of sampling (location, method, timing, intensity, and duration) varied considerably across strata and seasons. Assumption 2 is also questionable; the Jolly-Seber model allows for permanent emigration but not temporary emigration. If burbot are outside the sampling area in some years, then this assumption would be violated. It is unclear what effect this would have on abundance estimates. However, the sequence of between-season recaptures was consistent with consecutive spawning coupled with constant mortality (discussed below). Assumption 3 was likely satisfied. With respect to assumption 4, we used only between-season recaptures such that survival rates pertained to a period (roughly one year) greater than the sampling period. Across assumptions, violations of assumption 1 were likely the most serious. Nevertheless, results were generally consistent across models, including those with effort data and/or partitioned strata. Therefore, although we have limited confidence in any one annual estimate of abundance, it seems reasonable that overall averages and trends are reflective of historical conditions.

It is possible that tagged fish experienced greater mortality than untagged fish (assumption 5). Capture and handling of burbot resulted in ten reported deaths at the time of sampling, and two additional deaths were recorded within a few weeks of release, most likely due to the capture of fish from depths that made them susceptible to decompression trauma (Neufeld and Spence 2004). However, given so few recaptures it is not possible to directly test for immediate or sustained mortality due to tagging (Seber 1982, p. 230).

It is conceivable that relatively small fish experienced higher (delayed) mortalities due to capture and tagging, or that very large fish had high mortalities due to (implied) old age. To assess evidence of size-dependent mortality, we compared lengths of fish that were tagged but not recaptured with fish recaptured one or more seasons later (Figure 36). The two distributions had similar means (565 mm in each case), but there were lower proportions of small and large fish among the recaptures (Figure 36). As a result, the length distribution for recaptures had a lower standard deviation (84 mm vs. 111 mm), which was marginally significant ($P = 0.02$ and 0.05 for one-tailed and two-tailed F-tests, respectively). While this is consistent with hypotheses that relatively small or large fish experience higher mortality, it is difficult to draw a firm conclusion or speculate on mechanisms given the small sample size for recaptures.

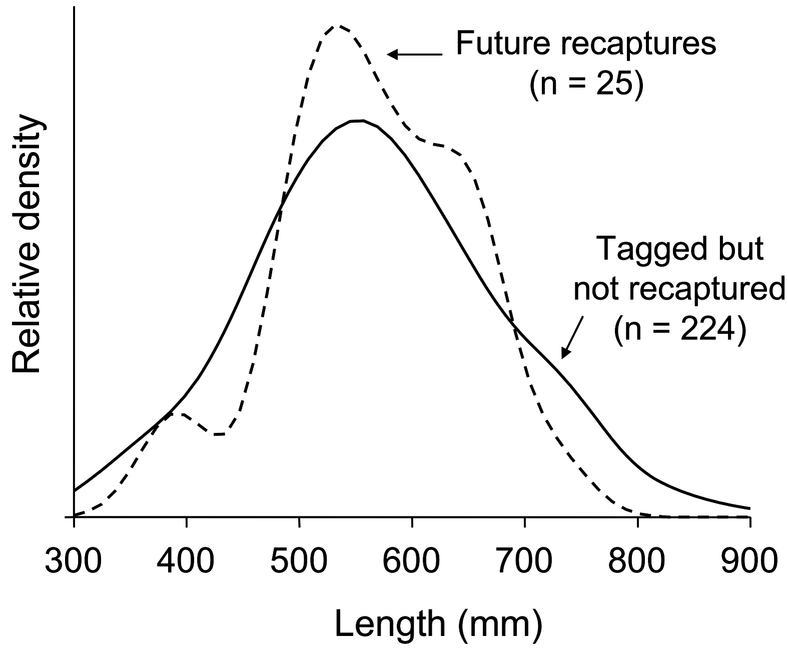

Figure 36. Initial length distributions for burbot tagged but not recaptured (solid line) and burbot recaptured after one or more seasons (dashed line) (strata 2-5, 1993-2003).

Numerous captures were implanted with sonic tags in addition to PIT tags. We hypothesized that additional stress due to surgical implant of sonic tags would increase mortality and therefore reduce recapture rates. From 1993 to 2003, 77 of 268 PIT-tagged burbot also received sonic tags (29%), but only two of the 24 between-season recaptures had received sonic tags (8%). A simple binomial test suggests this recapture rate for sonic-tagged burbot was significantly lower than expected by chance alone. However, this test does not incorporate obvious differences among strata in recapture rates and proportions of sonic-tagged burbot (most sonic tags were implanted in captures from strata 2 and 4). We therefore analyzed data for strata 2-5 in separate 2 x 2 contingency tables, and assuming independence among strata, summed the chi-square values (Seber 1982). Although the recapture frequency of sonic-tagged fish was lower than expected in all strata, the overall P-value was 0.07. Again, the evidence was merely suggestive.

Estimates of survival rate ($ø$) for the above models generally reflect the numbers of recaptures observed 1 to 4 seasons after last capture, which were 19, 5, 3, and 0, respectively. This sequence is consistent with consecutive spawning events (or persistence in the sampling area) and a survival rate of about 40%. However, a survival rate of 40% is not consistent with observed length distributions (discussed below) and more generally, with expected longevity of burbot. For example, $ø = 0.4$ implies an average life span ($= -1/\log[ø]$) of approximately 1 year from the time of capture (Seber 1982, p. 216). When survival of tagged fish is not representative of the general population, estimates of recruitment (B) are invalid. Here, we expect that estimated survival was low, and hence recruitment biased high.

Population Model

Initial parameters for the population model were based on empirical estimates from the growth and capture-recapture models. Specifically, LVB parameters were set at K = 0.05, L_∞ = 1,500, t_0 = -1, and $ø_w$ = 0.5. In this case, $ø_w$ reflects the standard deviation of lengths at a given age, which was assumed to be greater than the estimate for individual growth rates (Table 11). The survival rate ($ø$) was set at 0.4, and by default, all ages were assumed to have equal capture vulnerability (no selectivity). The observed length distribution, which the model attempted to approximate, was based on all captures for strata 2-5 (mean = 566 mm and SD = 108 mm).

The expected length-frequency given the initial parameter values was skewed strongly toward low lengths (Figure 37). This is easily anticipated. Under constant recruitment, there will be more fish in younger age classes. Thus, to approximate the symmetry of the observed distribution, relative capture vulnerabilities of younger fish must be reduced. However, it is also evident that few fish were expected to obtain lengths greater than 500 mm (Figure 37). In fact, there was no reasonable selectivity curve to reproduce the observed length distribution given the initial growth and survival parameters.

We present three scenarios in which growth and survival parameters were changed and then selectivity parameters (n_1 and n_2) were crudely estimated (Table 15). First, we increased the survival rate ($ø$) to 0.6, a value at the upper bound of confidence region presented in Figure 31. Estimates of selectivity parameters were roughly n_1 = 1.3 and n_2 = 7.4 (Table 15, Case 1), providing a reasonable approximation of the observed length distribution (Figure 38). However, this implied a slow increase in selectivity with fish at age ≈ 7 (mean length = 529 mm) having a 50% capture vulnerability. Across ages 3-12, the vulnerable proportion of the population was only 17% (Table 15, Case 1).

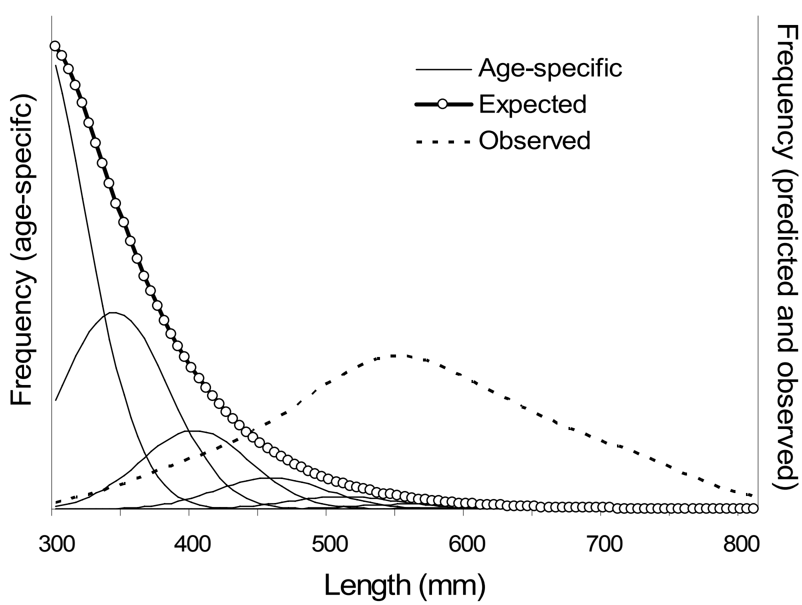

Figure 37. Length-frequency distributions (relative densities) for initial parameter values of the population model. The “expected” distribution integrates across age-specific distributions.

Table 15. Parameter values for different scenarios of the population model. Also shown are mean lengths at age n_2 (age of 50% vulnerability) and the vulnerable proportion of the population (ages 3-12).

	K	L_∞	t_0		n_1	n_2	Length at n_2	% Vulnerable
Case 1	0.05	1500	-1	0.6	1.3	7.4	529	17%
Case 2	0.18	850	0	0.4	1.5	6.0	561	18%
Case 3	0.18	850	0	0.6	1.5	5.0	507	51%
Case 4	0.18	850	0	0.6	2.5	4.0	436	78%, 89%

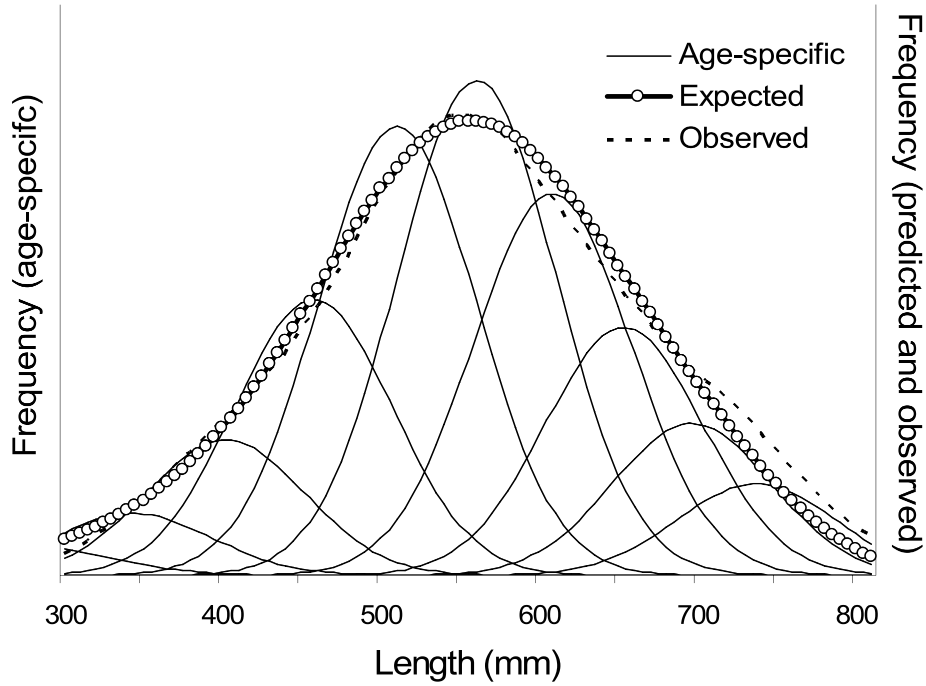

Figure 38. Length-frequency distributions given parameter values for Case 1 (see Table 15).

In the second scenario, LVB parameters were changed to $K = 0.18$, $L_\infty = 850$, and $t_0 = 0$ (with ø set back to 0.4). These parameters imply more rapid growth and correspond to the "example" parameter combination in Figure 27 and growth curve in Figure 28. This growth curve is very similar to that presented in Katzman and Zale (2000) for burbot from Lake of the Woods, Ontario, in the mid range of the populations. Again, however, the corresponding estimates for n_1 and n_2 implied very low capture vulnerabilities across ages (Table 15, Case 2).

The third scenario included both increased survival and growth rates, which yielded a more reasonable selectivity curve (Table 15, Case 3). The age of 50% capture vulnerability was 5 (mean length = 507 mm) and the vulnerable proportion of the population increased to 51%.

Last, we present a scenario in which recruitment (N_3) declined over time. The goal here was to roughly mimic the observed increase in mean length over time (Figure 24) via a simple exponential decline in recruitment. Again, high survival and growth rates were assumed, as well as a steeper selectivity curve (Table 15, Case 4). A large decline in recruitment was required to produce a shift in the length distribution similar to the observed shift. For example, a 30% decline per year resulted in a change in mean length from about 530 mm in year 1 to 600 mm in year 10 (Figure 39). Recruitment and total abundance in year 10 were only 4% and 10% of that in year 1, respectively. Interestingly, the decline and corresponding shift in age distribution allowed for greater capture vulnerabilities among younger age classes (age of 50% capture vulnerability was 4 with mean length = 436 mm). Consequently, for this scenario the vulnerable proportion of the population was 78% in year 1 and 89% in year 10.

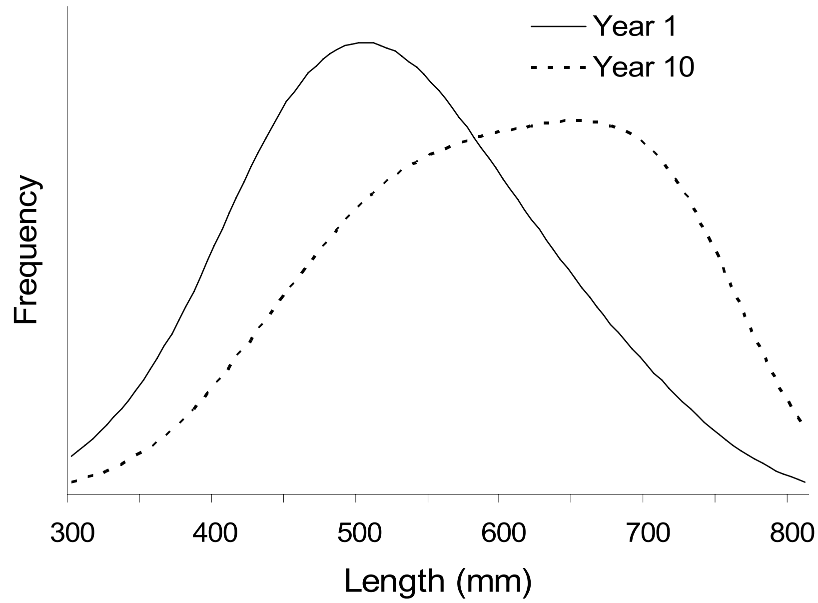

Figure 39. Expected length-frequency distributions in year 1 and 10 given an annual decline in recruitment of 30% with parameter values for Case 4 in Table 15.

DISCUSSION

Analyses of 12 years of capture-recapture data confirm that burbot numbers are very low, numbers are declining, recruitment is poor, and the population is on the threshold of extinction. This conclusion is supported by annual abundance and recruitment estimates, declining CPUE in population surveys, and an increasing trend in average fish size.

Average estimates of adult burbot abundance for 1997-2003 ranged from 150 to 200, depending on the model. Although these estimates were based on few recaptures and simplifying assumptions, they seem reasonable in several respects. For example, 12 years of sampling produced only 403 captures, of which 72 were recaptures. In recent years, there were fewer than 30 captures annually despite high sampling effort. Uncertainty in the average abundance estimate was quantified for only one model, though this result should generally be applicable and suggests a rough confidence interval from one-half to double the estimate. Of course, abundance estimates pertain only to the vulnerable portion of the burbot population in sample strata 2-5. For this reason, population estimates are likely conservative.

Catch rates for Kootenai River burbot are near the low end of values reported in other areas. Kootenai River CPUE ranged from 0.054 fish/net d in 1996 to a low of 0.008 fish/net d in 2004. Although gear types differed, the Kootenay Lake Balfour fishery CPUE was between 0.50 and 1.48 fish/hour (Redfish Consulting 1998). By comparison, CPUE in the Tanana and Chena rivers, Alaska, was greater than 1 fish/net day and 0.5 fish/net day, respectively (Evenson 1993). CPUE of burbot in four Alaskan Lakes ranged from 0.5 to 3.0 fish per net day (Parker et al. 1988).

Consistent capture of burbot occurred in only a few distinct areas: Ambush Rock, Idaho and in or near the Goat River, B.C. This occurred despite attempts to distribute effort uniformly.

However, these locations represent significant spawning locations. During the winter of 2000-2001, we captured over 20 burbot at Ambush Rock; both male and female burbot were identified as gravid, flowing, or spent. The highest catches of burbot in the Goat River occurred during this same time period and both gravid and spent fish were observed (Paragamian 1994a, 1994b; Paragamian 1995, 2000; Paragamian and Whitman 1996, 1997, 1998; Kozfkay and Paragamian 2002). There is no evidence of burbot spawning in other areas of the Kootenai River from Kootenay Lake to the Idaho-Montana Border.

Although there appears to be limited burbot movement between initial capture and recapture locations (Figure 16), these data may be misleading. Knowing the location of burbot at two discrete points in time, particularly when the time between capture and recapture is long, provides little information regarding movement patterns between capture events. Analysis of the capture and recapture locations is, however, suggestive of considerable site fidelity in Kootenai River burbot. In many cases, burbot were captured at the same location over multiple years, particularly in the Goat River and Ambush Rock areas.

Although burbot spawning and recruitment has been documented, observed declines in adult abundance and the general lack of small burbot (e.g., <500 mm) in recent years indicate that recruitment rates are too low to sustain a stable or growing population. Our simple burbot population model suggests that recruitment estimates from the capture-recapture model were biased high. In the population model, dramatic declines in recruitment were needed to reproduce a shift in the length distribution similar to that observed. The specific causes of poor recruitment are unclear; the relative significance of spawning stock limitation and poor incubation and survival conditions are unknown.

Length-frequency distributions of captures suggest reasonable growth estimates of adult burbot in the Kootenai River over the period 1993-2004. Burbot can be caught in hoop nets at about 350 mm TL but are not fully recruited until 450 mm TL (Bernard et al. 1991). The length distribution of burbot across 1993-2004 (Figure 18) was similar to that of burbot harvested in the Balfour fishery in Kootenay Lake from 1968-1975 (Redfish Consulting 1998). Although the most common length of Kootenai River burbot was between 500 and 600 mm compared to 650 to 750 mm for the Balfour fishery, there still were substantial numbers of burbot >700 mm captured since 1993. Furthermore, the population model indicated that growth rates consistent with the midrange of burbot populations reported in Katzman and Zale (2000) were needed to reproduce observed distributions (conditional on a constant adult survival rate of 60% and a reasonable selectivity curve). For this growth curve, lengths of 500 to 600 mm were dominated by ages 5 to 7. Lower growth rates would necessitate higher survival rates and would result in older fish in these length classes.

In contrast, survival rates were unexpectedly low. Capture-recapture estimates with a 40% annual survival rate are not consistent with observed length distributions and estimated individual growth rates. Such discrepancies may be because of sampling error or may reflect some adverse effects of capture, handling, and tagging on adult burbot.

These results indicate that the Kootenai River burbot may become extinct within the next decade and may already be past the point where recovery is feasible. Theoretical conservation biologists and geneticists estimate that a minimum effective breeding population (N_e) of at least 50 to 500 individuals is necessary to sustain a viable population (Soule 1980; Lande and Barrowclough 1987). Genetic and demographic risks and uncertainties of smaller numbers are very high. Genetic risks include the potential loss of rare alleles, drift in gene frequencies, increased genetic load from inbreeding, and a small population founder effect in the next generation. Demographic risks include too few spawners to take advantage of suitable habitat conditions, if they occur.

The acute imperiled status of the Kootenai River burbot population presents some difficult choices for conservation and recovery efforts. Current voluntary efforts to maintain low winter flows, thought to be conducive for burbot migration and spawning, have failed to arrest population declines or to restore significant burbot recruitment. It is unclear whether this failure results because flow measures fell short of necessary levels (Paragamian 2000; Paragamian et al 2005), recruitment is not only flow limited, primary and secondary river productivity is now reduced, the river is warmer in the winter, or other physical or biological changes in the system have rendered flow effects moot. Even if suitable habitat conditions can be immediately restored, recovery of the small remnant population may be precluded by genetic and demographic bottlenecks. Capture and artificial propagation of the last few wild individuals might be an option, but effective burbot propagation methods have yet to be developed. Supplementation or reintroduction of burbot from other healthier populations is yet another alternative, but nonnative stocks might fare poorly and speed extinction of the locally adapted native population. Finally, without diagnosis and restoration of suitable habitat conditions for burbot, all conservation, recovery, or reintroduction measures are likely to meet with limited success. Further, the value of additional burbot sampling activities may be questionable past the point of diminishing returns on new information gained. Yet monitoring the population with restoration measures in place may be critical.

RECOMMENDATIONS

1) Analysis of the demographic status of burbot in the Kootenai River will be periodically necessary in the future to monitor, in detail, critical changes to vital statistics (e.g., cohort contributions, total annual mortality, growth) and needs for improvement in rehabilitation efforts.

2) Although habitat changes are still the most important issues to rehabilitation of burbot, it is unlikely the Kootenai River burbot population can sustain itself or improve the present status. Thus, it will be necessary to rehabilitate burbot through supplementation or reintroduction of burbot from other healthier populations.

3) Genetic and demographic risks and uncertainties of smaller numbers of burbot are very high, including the potential loss of rare alleles and founder effect. Thus, any introductions from a donor stock need to have similar phenotypic as well as genotypic similarities to ensure the best compatibility possible to the native stock.

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